NASA Contractor Report 3012

The Verification of Landsat Data in the Geographical Analysis of Wetlands in West Tennessee

John Rehder and Dale Quattrochi

CONTRACT NAS8-31143
JUNE 1978

NASA

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The Verification of Landsat Data in the Geographical Analysis of Wetlands in West Tennessee

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Prepared for
George C. Marshall Space Flight Center
under Contract NAS8-31143

National Aeronautics
and Space Administration

Scientific and Technical
Information Office

1978

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CHAPTER I

INTRODUCTION AND PURPOSE

Resource managers in the United States have become increasingly concerned with the preservation of the interface between water and land as a critical component in the balance of the Earth's ecosystem. In the lexicon of ecology this gradation from water to land is defined as a wetland. Wetlands are referred to by a variety of names such as bogs, marshes, swamps, potholes, sloughs, wet meadows, and playas. In this report the only term used as a synonym for wetland is "swampland".

Inland and coastal swamplands in the United States are disappearing at a precipitous rate. Urban and agricultural encroachment, channelization, and draining have decimated extensive areas of wetlands, with only a fraction of the estimated original national total of 127 million acres (51 million hectares) of swamplands remaining.[1]

Through the efforts of research, a new cognizance for the importance of wetlands as components in the global ecosystem has emerged. Scientific evidence indicates that a myriad of plant and animal species depend on wetlands as a life support system; swamplands are also extremely beneficial to the general welfare of man:

> Wetlands moderate extremes in water flow and have value as natural flood-control mechanisms. They aid in water purification by trapping, filtering, and storing sediment and other pollutants and by recycling nutrients. Many serve as ground-water recharge areas. All function as nursery areas for numerous aquatic animal species and are critical habitat for a wide variety of plant and animal species. Wetlands produce economically important crops of fur, fish, wildlife, timber, wild rice, wild hay, wild cranberries, and other products. Many return profits through fees for hunting, fishing, and trapping privileges.[2]

Because of the increased awareness of wetlands as a vital natural resource, environmental managers at all levels of government have launched an effort to protect the nation's remaining inland and coastal swamplands. Paramount to the wetlands preservation endeavor is the classification and inventory of swamplands. The Office of Biological Services of the U.S. Fish and Wildlife Service is spearheading a national wetlands cataloging program. This project, begun in 1974, is designed for implementation at a broad level to collect data that will be useful to a wide audience of resource management agencies.

The ultimate purpose of the National Wetlands Classification and Inventory is to provide a basis for making decisions concerning swamplands management. In making decisions on the preservation of wetlands it is of primary importance to assess the social productivity of wetlands in their natural condition as compared to their social productivity in an altered or developed condition. Resource managers are faced with the problems of weighing the social benefits of preserving wetlands as critical habitats for wildlife, as water purification and recharge areas, as buffer zones against flooding, and for aesthetic values, versus the social advantages that can be realized from the alteration of swamplands.[3] The quantity and quality of benefits that can be obtained from the protection of swamplands primarily depends upon the nature and location of the wetland. The requisite data needs for resource management decision-making on wetlands preservation at the local, state, and national level, therefore, fall within two general categories: 1) basic research information for the establishment of decision-making criteria; and 2) near-real time data collection to provide information for the inventory, classification, and monitoring of wetlands.[4]

Remotely sensed data can be utilized as a fundamental tool for satisfying the wetlands information needs in both of these categories. Important decision-making criteria such as land uses and land-forms in the wetlands vicinity can readily be measured and evaluated using remote sensing techniques. Remotely sensed imagery is also a useful tool to resource managers as a medium for supplying near-real time data for the inventory, classification, and monitoring of wetlands. Through the application of remotely sensed imagery for wetlands information collection and retrieval, four benefits can be realized: 1) a reduction in costs and manpower for extensive field work; 2) the facilitation of inventory and mapping procedures; 3) an increased efficiency in detecting and monitoring change; and 4) the collection of multipurpose data that is pertinent to resource decisions on future wetland or non-wetland projects.[4]

PURPOSE OF THE STUDY

Although remote sensing techniques can be applied to the study of wetlands, the cost of obtaining aerial photography on a regular basis is prohibitive to most state and local resource management agencies. The imagery taken by NASA's Landsat spacecraft, however, is a viable alternative to wetlands data acquisition by airborne photographic sensors. Landsat provides repetitive aerial information at a moderate cost in comparison with the expenditure to fly and develop air photos. Nevertheless, resource management agencies have been reluctant to utilize Landsat imagery as a data source for wetlands analysis. This hesitation is based on two prinicipal beliefs: 1) that the resolution of the imagery severely limits the use of Landsat data for the

study of swamplands; and 2) that sophisticated, elaborate, and costly computerized equipment is necessary to extract and interpret wetlands information from Landsat imagery.

Resource managers at the federal, state, and local levels within Tennessee desire comprehensive geographic, environmental, and cartographic data on the State's wetlands, but question the value and utility of Landsat imagery for meeting their information needs. Data acquisition on the extensive area of inland wetlands in western Tennessee is of primary importance in an inventory of the State's swamplands.[5] The purpose of this report, therefore, is to illustrate the applications of Landsat imagery as an accurate medium for detecting, identifying, measuring, and mapping wetlands in West Tennessee using simple, manual techniques for interpretation.

STUDY AREA: GENERAL DESCRIPTION

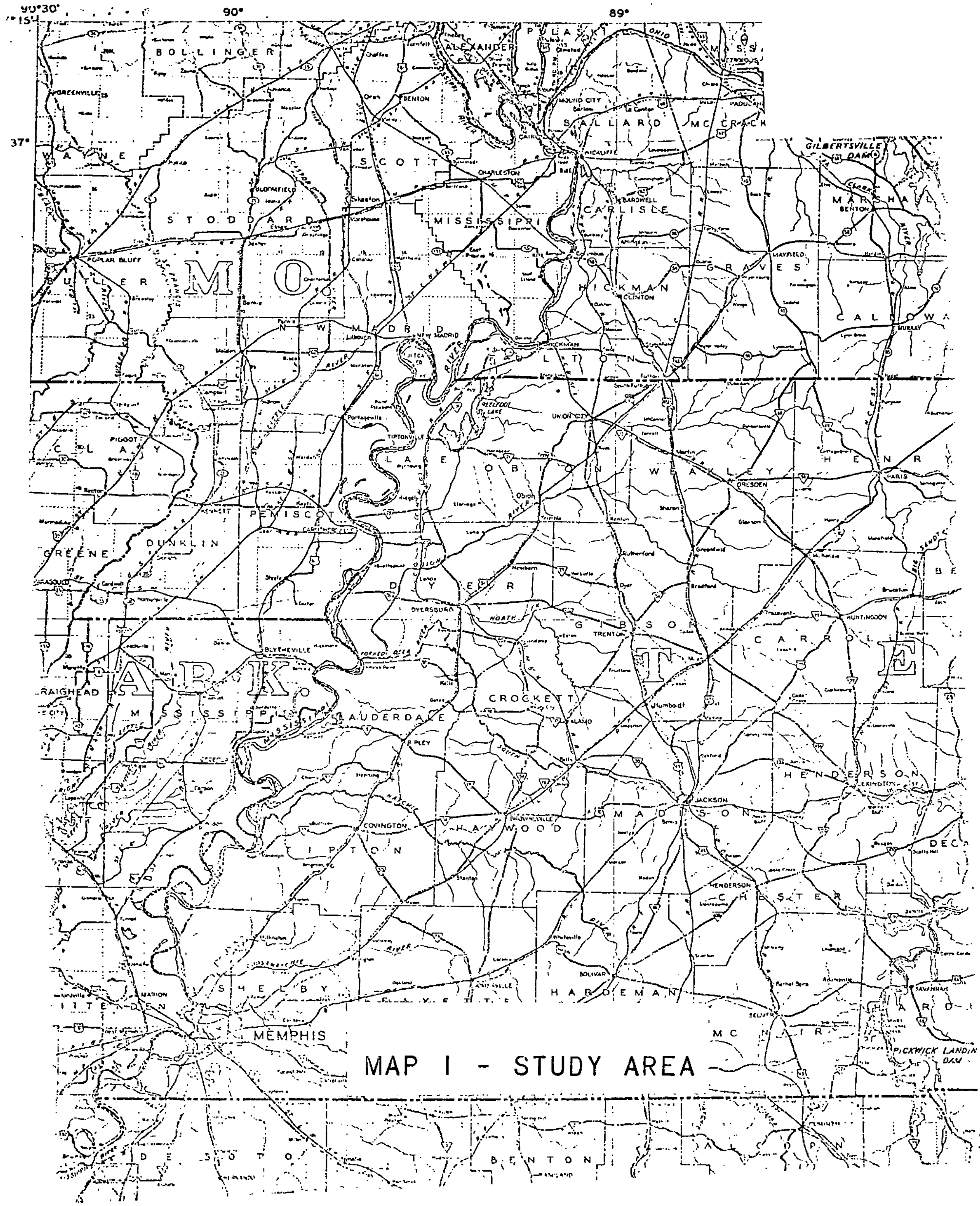
The physiography of the western Tennessee wetlands study area is separated into three natural divisions: the West Tennessee Uplands; the West Tennessee Plains; and the Mississippi Alluvial Valley.
The West Tennessee Uplands extend from the Tennessee River Valley on the east to approximately Jackson, Tennessee on the west. The width of the Uplands varies from about 12 miles (19 km) in the north to 40 miles (64 km) in the south. Topographically, the 4,300 square miles (11,146 square km) covered by the West Tennessee Uplands (about 43 percent of western Tennessee) consists of dissected hills with some undulating, gently sloping plains; streams in the area flow through unconsolidated material and have unstable banks.[6]

The West Tennessee Plain, which comprises approximately 48 percent (47,000 sq. miles or 121,830 sq. km) of the West Tennessee area, slopes gently for 50-55 miles (80-88 km) from the western border of the Uplands to the western edge of the Loess Bluffs that overlook the Mississippi Alluvial Valley. These bluffs have an elevation of 350-400 feet (106-122 m) and stand 130 feet (39 m) above the Mississippi River floodplain. They extend 15-20 miles (24-32 km) eastward and have a terrain that is heavily dissected by streams which have cut narrow, steep valleys into the unconsolidated loessial deposits.[6] The topography of the West Tennessee Plain east of the Bluffs is undulating and gently rolling. Rivers in the area are wider and more sluggish than in the Uplands, and their flow is impeded by sediment caused by sheet erosion and gullying.

The Mississippi Alluvial Valley is a low plain that covers approximately 900 square miles (2,333 sq. km) of West Tennessee. The Valley is bordered on the west by the Mississippi River and on the east by the Loess Bluffs. The Alluvial Plain coincides with the high water level of the Mississippi River and is marked by a levee which parallels the northern two-thirds of the River in West Tennessee.[6]

STUDY AREA: THE WETLANDS

The wetlands of West Tennessee are associated with Reelfoot Lake, the Obion, Forked Deer, and Hatchie Rivers, and the Mississippi Alluvial Floodplain (Map 1). Two other rivers in West Tennessee, the Wolf and the Loosahatchie, also have limited areas of wetlands within their basins, but the focus of attention by resource management agencies has been on wetland areas other than along these streams. The Wolf and the



MAP I - STUDY AREA

Loosahatchie River wetlands, therefore, have been excluded from the scope of this study.

The Obion-Forked Deer River Basin

The Obion, Forked Deer, and Hatchie Rivers act as the principal drainage systems of the land between the Tennessee and Mississippi Rivers within the study area. Both the Obion and Forked Deer Rivers consist of a main channel which branches into three primary tributaries designated as the North, Middle, and South Forks; the main river channels also meet and form a common outlet into the Mississippi River.

The bottomlands of the Obion and Forked Deer Rivers have soils which are poorly drained as a result of alluvial deposition. Soils are extremely fertile and support a lush swampland vegetative growth. Wetland vegetation consists primarily of oak, gum, cypress, elm, ash and cottonwood; some willows, hickories, and maples are also mixed with the dominant hardwood vegetation. The extent and volume of these hardwood stands have been reduced by a number of natural, man-made, and man-induced phenomena.

Agricultural encroachment and channelization have had an extremely pernicious affect on wetlands within the Obion-Forked Deer River system. The bottomlands of these rivers with their highly productive soils are prime areas for agriculture. Consequently, extensive agricultural encroachment has taken place within the Obion-Forked Deer River bottoms which has destroyed much of the original wetlands along these streams. Large-scale channelization of the Obion and Forked Deer Rivers has expedited the draining of the bottomlands for agricultural clearing. Piecemeal channelization of these streams began approximately 60 years

ago and accelerated in the 1950's when soybeans became the chief cash crop of West Tennessee. Wide-spread encroachment into the bottomland wetlands came in the 1960's to facilitate the extensive, highly mechanized soybean farming operations in the area.[5]

Sheet erosion caused by land clearing and channelization has accelerated the destruction of the wetlands. Erosion from the cleared uplands and bottomlands in the Obion-Forked Deer basin has resulted in an increase of suspended and bed loads in the river channels and has impaired the water quality of the streams. Sedimentation together with poor channel maintenance has significantly reduced the carrying capacity of the river channels to the extent that flooding is a severe problem within the Obion-Forked Deer River systems. During periods of heavy rain, rapidly moving water reaches the sediment-laden areas of the channels causing the rivers to overflow. Sediment deposits have also formed natural levees along the rivers which hinder the flow of water back into the channels and create ponded conditions in the floodplains.[7] The sediment deposition in these ponded areas has adversely affected the hardwood vegetation of the bottomlands.

An increase in the beaver population within the area has aggravated the flooding conditions caused by erosion. Beaver colonies have constructed dams across channels which impound water for periods far in excess of the tolerance of many hardwood species.[5]

Urban encroachment along the Obion and Forked Deer Rivers has also devastated much of the wetlands in the basin. The expansion of built-up land around the urban population centers, particularly at Jackson and Dyersburg, has consumed large areas of wetlands. Additionally, clearings for highway, railroad, pipeline, and electrical power transmission

rights-of-way have taken up significant areas of wetland vegetation within the Obion-Forked Deer basin.

The Hatchie River Basin

The Hatchie River in contrast to the Obion and Forked Deer Rivers, is unchannelized; thus, clearing and draining of the wetlands along the Hatchie River has been impeded, and the swamplands which are similar in vegetative composition to those found in the Obion-Forked Deer basin, have not been drastically altered. Topography has also prevented the large-scale encroachment of agricultural acitivity into the Hatchie River bottomlands. Steep slopes rise from the bottomlands and gradually give way to rolling uplands. The terrain immediately surrounding the Hatchie River wetlands is not conducive to extensive agricultural mechanization practices and the destruction of the stream's swamplands, therefore, has been hindered in part by the rugged relief in the area. In places along the Hatchie where the terrain is suitable for agriculture, encroachment into the wetlands has taken place, but this is confined primarily to a few areas along the western portion of the river near its confluence with the Mississippi. Patches of agricultural clearing are also evident along the natural levees within the Hatchie basin where the soils are well drained in comparison to the poorly drained soils of the bottomlands. In addition to the topographic barriers which prevent agricultural encroachment into the wetlands, the Hatchie has been designated a Scenic River by the State of Tennessee. Hence, any further destruction of the Hatchie River environment is precluded by law.

Erosion and sedimentation in the Hatchie River basin do not present any large scale problems, since the Hatchie is unchannelized and clearing

for agriculture is not widespread. Beavers, however, are a nuisance in the basin, particularly in the tributary areas of the river. As a result of the animal's activity, there as been an increase in the amount of timber kill within the main floodplain.[5]

Urban encroachment into the Hatchie River wetlands poses no significant problem to the basin's swamplands except at Bolivar, Tennessee, where built-up land has penetrated into the forested bottomlands. The construction of highways through the basin has also destroyed and altered some areas of wetlands along the Hatchie. Borrow pits and grading activity for the construction of Interstate 40 and State Route 76 have eliminated some wetland vegetation, and have impounded water which is destructive to hardwoods in the bottomlands.

Reelfoot Lake

Reelfoot Lake, located at the northern edge of the Mississippi Alluvial Valley, is a tectonic feature created by the New Madrid Earthquake of 1811-12.[8] The lake and its surrounding wetlands are protected as part of the Reelfoot National Wildlife Refuge, and by the State as a fish and game preserve. The lake's wetlands are comprised mainly of cypress and other hardwoods with some shallow water areas covered by a variety of aquatic plant life.

The Mississippi Alluvial Valley

As one of the most fertile agricultural areas in the entire state, the Mississippi Alluvial Valley of West Tennessee is heavily cultivated with the land utilized for soybean, corn, and cotton production, and pasture for cattle. Isolated patches of wetlands that have escaped

obliteration by clearing and draining practices dot the Alluvial Valley. These small swampland tracts are generally confined to the area north of the Obion-Forked Deer River confluence with the Mississippi River, where earthen levees have been constructed to protect the agricultural land from flooding. Despite the system of levees, the lowlands are subject to widespread inundation during periods of high rainfall.

In the Mississippi Alluvial Valley to the south of the Obion-Forked Deer confluence there are no levees, and consequently, the wetlands are more extensive. The larger tracts of wetlands throughout the Alluvial Valley, however, have been preserved primarily because they are used as state or federal wildlife management areas or as private game reserves. The region is in the heart of the Mississippi Flyway with protected areas, such as the Anderson-Tully State Wildlife Management Area located north of the mouth of the Hatchie, the Moss Island State Waterfowl Refuge which borders the Obion-Forked Deer River on the north near the stream's confluence with the Mississippi, and the Lake Isom National Wildlife Refuge located just south of Reelfoot Lake, serving as a haven for a variety of waterfowl and wildlife.

Although preserved areas like those in the Mississippi Alluvial Valley have been established to maintain wetland habitats for fur, fish, and fowl, unprotected swamplands within the West Tennessee study area are plagued with a plethora of natural and man-related problems that threaten their existence. Resource management agencies need reliable, up-to-date information on the swamplands so that ecologically sound, rational decisions can be made on how to best protect or utilize these wetlands. Landsat imagery as a medium for detecting, identifying, measuring, and mapping swamplands can help meet the data requirements of resource man-

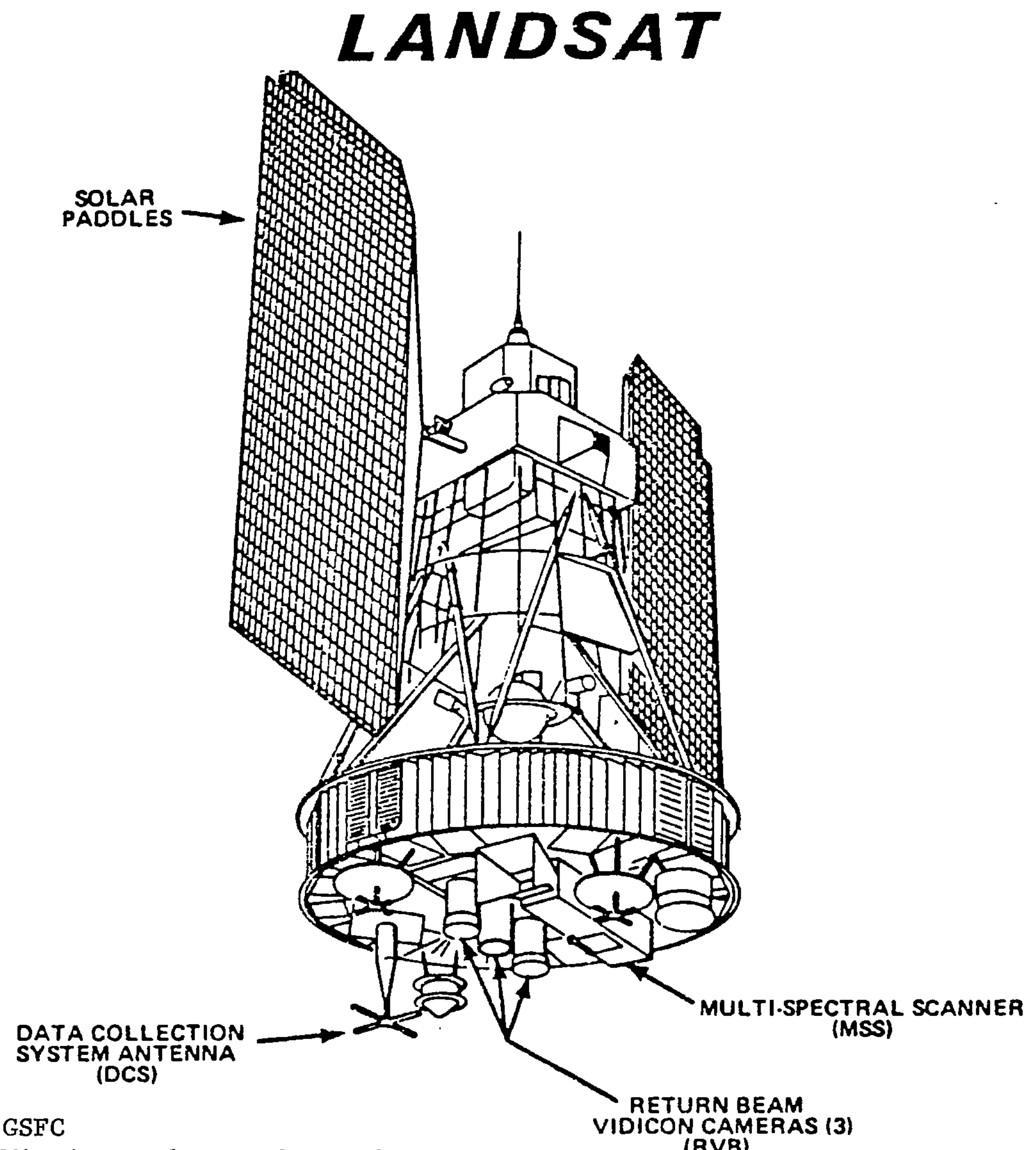
agers for comprehensive cartographic and geographic information on the wetlands of West Tennessee.

DESCRIPTION OF THE LANDSAT SYSTEM

NASA's Landsat I (formerly the Earth Resources Technology Satellite or ERTS-1) and Landsat II were launched into circular, sun-synchronous, near-polar orbits of 560-570 miles (902-918 km) altitude, on July 23, 1972 and January 22, 1975 respectively.[9] The spacecraft circle the Earth every 103 minutes, or approximately 14 times per day, and provide repetitive coverage of the same area on the globe every 18 days by each satellite. With two Landsats in tandem orbits nine days apart, any point on the Earth's surface between 82 degrees north and south latitude will be passed over by the satellites every nine days.[10]

Both spacecraft are equipped with three data acquisition systems; 1) a return beam vidicon (RBV); 2) a multispectral scanner (MSS); and 3) a data collection system (DCS) (Figure 1). The RBV system is comprised of three video cameras that are designed to "televise" imagery back to Earth. Shortly after launch, the RBV systems were deactivated because of electrical problems.[10]

The primary sensor of the Landsat system has become the MSS, a four channel continuous-line scanner. The device utilizes an oscillating mirror to reflect the ground image onto an array of six detectors in four spectral bands individually referred to as bands 4, 5, 6, and 7 (Figure 2).[11] Each band operates within different "windows" or "slots" in the electromagnetic spectrum. Through these windows, the MSS senses visible and infrared energy emitted from the Earth that can be used to



GSFC
Mission and Data Operations

Figure 1.

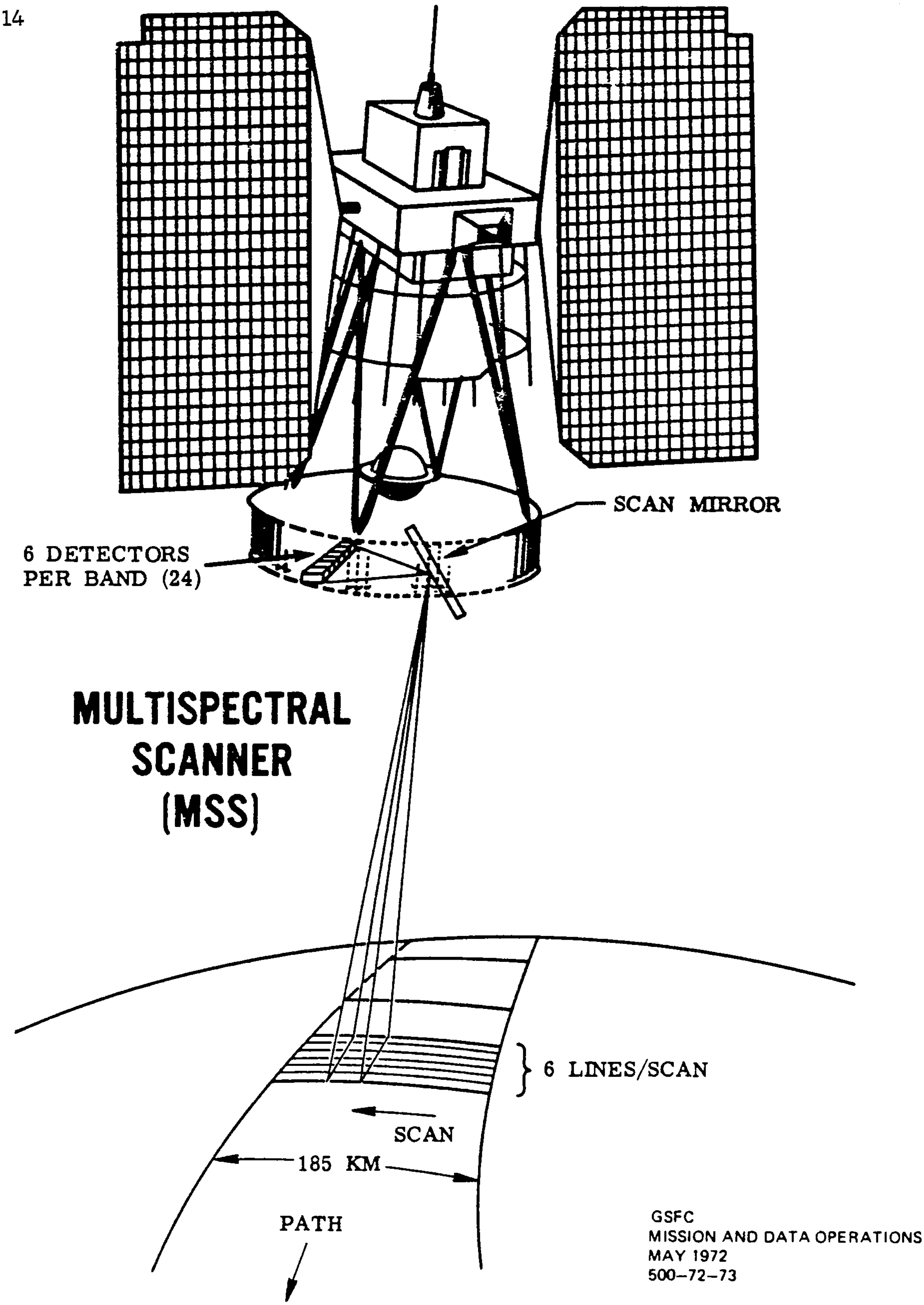

SCAN MIRROR
6 DETECTORS PER BAND (24)
MULTISPECTRAL SCANNER (MSS)
6 LINES/SCAN
SCAN
185 KM
PATH
GSFC
MISSION AND DATA OPERATIONS
MAY 1972
500-72-73

Figure 2.

detect various physical and cultural features. The four spectral bands are divided into the following spectral wavelengths:

Band 4 (green band) - 0.5 to 0.6 micrometers; emphasizes sedimentation in water and delineates areas of shallow water such as shoals, reefs, or sandbars.

Band 5 (lower red band) - 0.6 to 0.7 micrometers; facilitates the detection of cultural features in contrast to vegetated surfaces.

Band 6 (lower red and near-infrared band) - 0.7 to 0.8 micrometers; facilitates the detection of boundaries between land and water, and landforms.

Band 7 (near infrared band) - 0.8 to 1.1 micrometers; provides good penetration of atmospheric haze, and facilitates the detection of the boundary between land and water, and landforms.[9]

The detectors in the MSS measure the brightness of an image element or pixel which is 187 feet (57 m) long by 259 feet (79 m) wide on the ground. The MSS assembles the pixel scan lines into a scene that is 115 miles (185 km) on a side or approximately 13,225 square miles (34,225 sq. km) in area.[11] Electronic signals from each detector are transmitted to a ground receiver and recorded on magnetic tape. These signals are translated into four black and white spectral images, one for each band, and printed on 70 mm film. From this 70 mm format negative which represents a scale of 1:3,390,000, the MSS data is processed into black and white or false color composite imagery at 1:1,000,000, 1:500,000, and 1:250,000 scale. False color (simulated color infrared) imagery is produced by exposing three bands (4, 5, and 7) of MSS 70 mm imagery through different color filters onto color film.

Two general types of Landsat data are available: bulk and precision processed imagery. Bulk or systems-corrected imagery is positioned over the Earth scene by orbital data. Precision-processed or geometrically corrected imagery is produced by adjusting the scanner data to ground

control points; the resultant imagery with geometric distortions mitigated or eliminated conforms to a true orthographic projection. Despite the geometric accuracy of the imagery, precision-processed data lacks the clarity and sharpness of detail found in the bulk MSS imagery.

Landsat data in digital form are available in seven or nine track Computer Compatible Tapes (CCTs). Four CCTs are required to digitally process one Landsat image; the positioning of the data on the tapes necessitates the utilization of all four tapes to complete a set.

The Landsat DCS receives and re-transmits information from ground-based data collection platforms. Environmental, meterological, climatological, and geologic data are transmitted from the earth-based sensors to Landsat as the spacecraft orbits overhead. The data are sent to an analysis facility at Goddard Spaceflight Center in Greenbelt, Maryland where the information is processed for distribution to interested agencies and individuals.

One major advantage of Landsat imagery besides providing up-to-date multispectral earth resources information is its cost. The expenditure needed to acquire Landsat imagery is minimal in comparison to the financial outlay required to obtain aircraft data. Landsat 1:1,000,000, 1:500,000, and 1:250,000 scale, black and white print data costs \$3, \$8, and \$15 respectively; color composite print imagery costs approximately two and one half times more than black and white data. On the other hand, one 9 x 9 inch (23 x 23 cm), 1:130,000 scale, color infrared transparency from a NASA aircraft mission costs \$12. The monetary outlay needed to obtain timely, repetitive aircraft imagery for monitoring dynamic natural resources, such as wetlands, would be prohibitive. Multispectral, near-real time Landsat imagery with its low cost and "big

picture" format, therefore, can be a boon to resource managers who require comprehensive cartographic and geographic data on the wetlands of West Tennessee.

BACKGROUND

The use of Landsat data to study and map coastal and inland wetlands in the United States has been documented by a number of investigators. These researchers have employed a variety of interpretation techniques, such as the image enhancement and digital processing of Landsat data, for wetlands analysis. Recent work by Carter, McGinness, and Anderson, and Klemas illustrates the utility of Landsat imagery for wetlands mapping.

Carter et al. examined the applications of Landsat data to wetlands analysis along the Atlantic Coast using several image enhancement and mechanical interpretation techniques.[12] These researchers found that Landsat 1:1,000,000 scale band 5 and 7 data enlarged to 1:250,000 scale using a Bausch and Loomb Zoom Transfer Scope permitted the practical delimitation of large wetland areas. (Mention of a specific product name does not imply endorsement by The University of Tennessee, NASA, or the authors.) Further enlargement of the imagery to 1:125,000 scale provided more specific information than could be acquired at 1:250,000 scale. An additional manual interpretation technique which utilized a Diazo color subtractive procedure for analysis of band 7 or color composite Landsat data yielded wetlands features that were easy to map. Carter et al. also utilized density slicing, automated theme extraction, and digital processing techniques to study wetlands. These interpretation methods involve the use of sophisticated computer hardware and

software which either electronically generate maps directly from Landsat data, or accentuate swamplands to facilitate the visual mapping of wetlands from the imagery. Klemas and his colleagues have investigated the cartographic reliability of Landsat data for mapping the coastal wetland resources of Delaware.[13] Digitally processed Landsat imagery was utilized to inventory and map the swamplands. A computer analysis identified and mapped eight selected categories of wetlands vegetation with accuracies ranging from 52 to 100 percent in comparision with ground truth data. In another study, Klemas found that the automatic theme extraction of Landsat CCT data yielded accuracies of over 80 percent for the wetlands area tested in relation to a 1:133,000 scale map and a 1:60,000 scale aerial photograph of the Delaware coast.

Research on the utilization of Landsat data for inland wetland analysis can be exemplified by the investigations of Carter and Smith, Frazier, Keifer, and Krauskopf, Seevers et al., and Cartmill. Carter and Smith studied the applications of Landsat imagery for wetlands vegetation mapping in the Great Dismal Swamp of Virginia and North Carolina and the Big Cypress Swamp of southern Florida.[4] Landsat data provided single frame, large area coverage of the Dismal Swamp and aided in the selection of test sites within the Swamp. The imagery was also useful in the collection of hydrologic data, the detection of swampland change characteristics, and the mapping of wetland vegetation. Carter and Smith also experimented with the automatic theme extraction of the Great Dismal Swamp from Landsat CCTs, and the utilization of Landsat DCS information to facilitate water management studies in southern Florida.

Frazier, Kiefer, and Krauskopf prepared a 1:500,000 scale wetlands map of Wisconsin from Landsat multispectral data utilizing an additive

color viewer (i.e., image enhancement technique) as a medium for interpretation.[14] These researchers' mapped the state's wetlands according to three landform classes: organic (muck/peat), outwash and lacustrine, and mixed (included organic, ablation till, and lacustrine). Cartographic accuracies of 91.70 percent, 59.30 percent, and 56.90 percent were achieved for each of the three classes respectively. Ground truth data for control were obtained from topographic maps.

In another study, Seevers et al. used 1:250,000 scale positive print enlargements of Landsat band 5 and 7 data to map four categories of wetlands in Nebraska.[15] Electronic enhancement of band 6 imagery allowed further differentiation of swamplands. Seevers et al. found that it was possible to delineate wetlands of ten acres (4.05 hectares) or larger in size on Landsat data with an accuracy of 85 percent, based on information obtained from color infrared aerial photography.

Cartmill, in his study of swamplands in the Atchafalya River basin of Louisiana, utilized automated data extraction techniques to delineate wetlands from Landsat CCTs.[16] For the swampland and corresponding land use categories tested, this digital theme extraction procedure correctly classified 77.5 percent of the Landsat training samples selected for the investigation.

These examples of current research on wetlands analysis illustrate that swamplands can be detected and mapped with accuracy from Landsat data. None of the research surveyed, however, relied principally on simple, manual interpretation techniques for delimiting wetlands from Landsat imagery, or focused on an analysis of swamplands in West Tennessee. Image enhancement and digital processing of Landsat data require electronic equipment that is costly to purchase and operate.

On the other hand, manual techniques may require more man-hours for interpretation, but utilize equipment that is readily available at a reasonable cost and is simple to operate by a wide range of users.

Perhaps the greatest drawback to utilizing simple, visual interpretational techniques for measuring and mapping wetlands from Landsat imagery is the question of their reliability. This investigation, therefore, will not only examine the utility and accuracy of Landsat imagery for wetlands analysis in West Tennessee, but will also demonstrate the applications of manual interpretational techniques for the study of swamplands from Landsat data.

PROCEDURE: GENERAL DESCRIPTION

The verification procedure developed for this study was predicated on the visual interpretation and measurement of multispectral/multiscaled imagery. The wetlands of West Tennessee were initially mapped from multi-temporal, Landsat bands 4, 5, 6, 7, and color composite 1:1,000,000 scale imagery. One Landsat image date was selected as a data base for the verification analysis. A geographic coordinate system was then used to evaluate the planimetric accuracy of the imagery in relation to National Map Accuracy Standards. Fourteen test sites were selected from the Landsat imagery as data control calibration parameters to assess the accuracy of the imagery for measuring and mapping wetlands in West Tennessee. Low altitude color infrared aerial photography was utilized as ground truth in the verification testing procedure. The wetland areas within the test sites were measured for comparisons between the aerial photography and multi-scaled Landsat data. Percentages of areal and linear accuracy were computed for the total wet-

land area measured within the test sites from the aerial photography and the Landsat imagery. To further test the accuracy of the Landsat imagery for mapping and analyzing wetlands in West Tennessee, an overall measurement of the swamplands was performed and the results compared with measurements taken from high altitude aerial photography of the wetlands study area.

CHAPTER II

WETLANDS MAPPING FROM MULTISPECTRAL/MULTISCALE LANDSAT IMAGERY

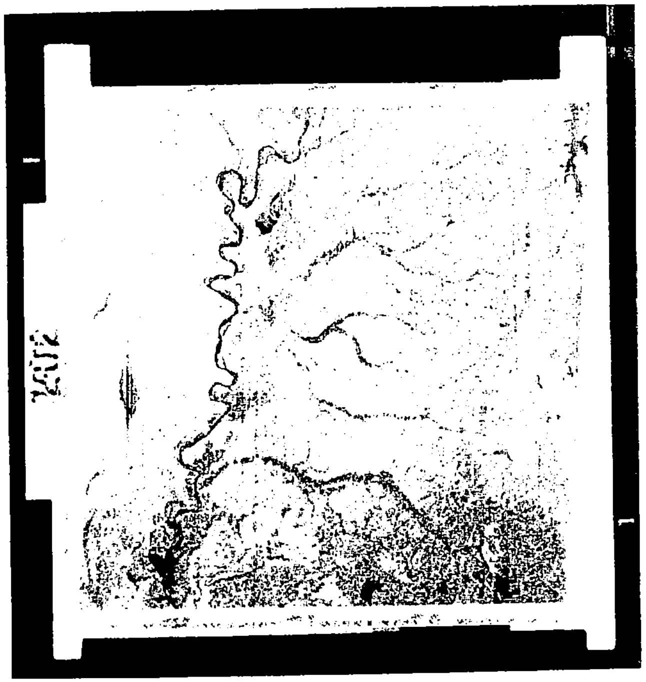
As a prologue to the Landsat accuracy testing procedures developed for this study, the West Tennessee wetlands were mapped from multiseasonal, multispectral Landsat imagery. Landsat bands 4, 5, 6, 7 and color infrared composite 1:1,000,000 scale imagery for September 13, 1972 (I.D. #1052-16055), February 22, 1973 (I.D. #1214-16065), and May 5, 1973 (I.D. #1286-16065) were used to depict the wetlands at low, median, and high water stages respectively (Figures 3-5).

This mapping procedure was performed prior to verification testing of Landsat for several reasons: 1) to initially discern whether or not the West Tennessee wetlands could be identified and mapped from the Landsat imagery; 2) to formulate a basis for classification of wetlands from the satellite data; 3) to monitor inter-image and intra-image variations in wetland signatures; and 4) to assess the general and specific cartographic problems that would be encountered when mapping wetlands from Landsat.

Identification of Wetlands from Landsat Imagery

The first priority of the study was to establish whether or not wetlands were identifiable and mappable from the multispectral, multiseasonal satellite imagery. An empirical analysis of the Landsat data illustrated that the wetlands of the Obion, Forked Deer, and Hatchie Rivers, Reelfoot Lake, and the Mississippi Alluvial Valley lowlands

SEPT. 13, 1972



COMPOSITE OF 4,5,7

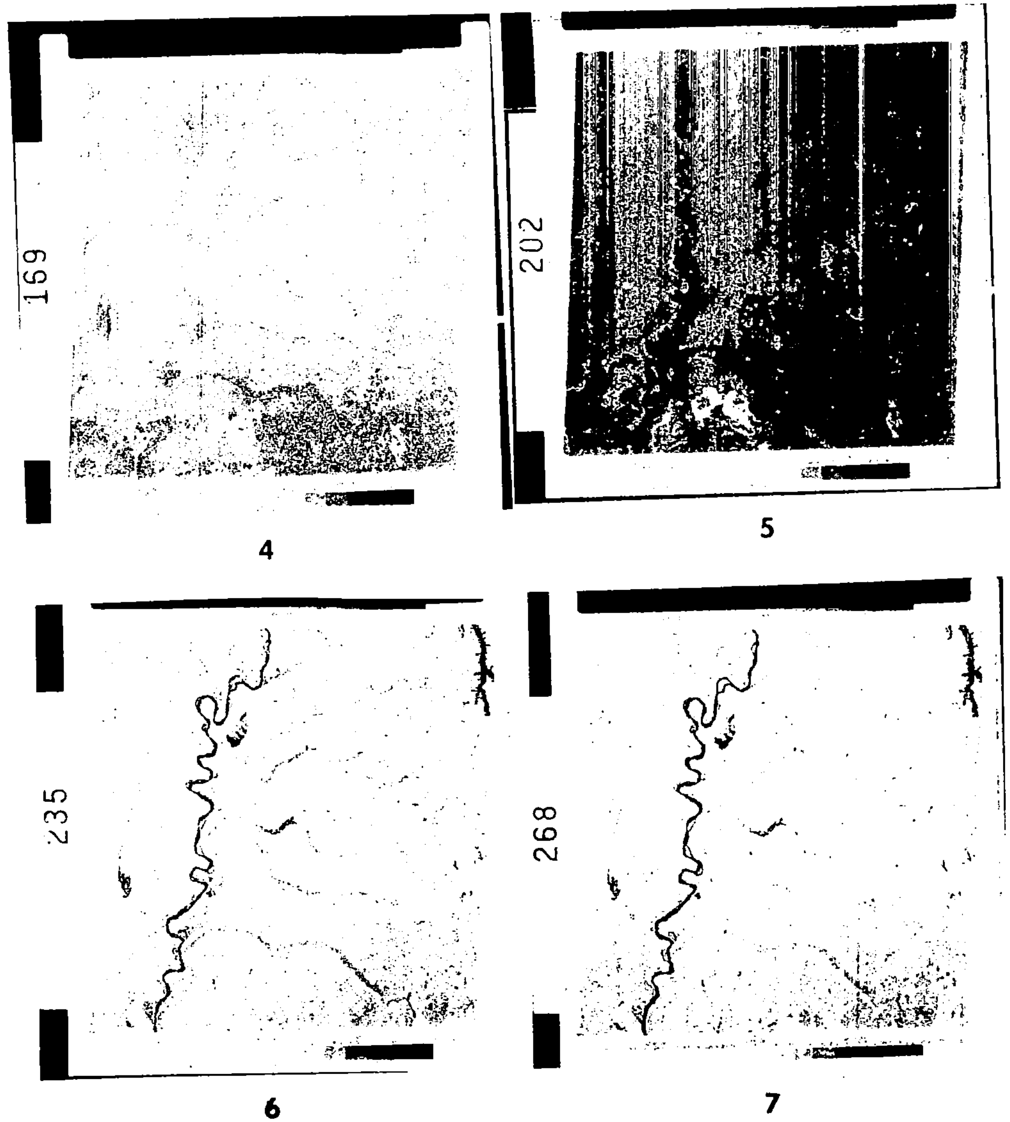


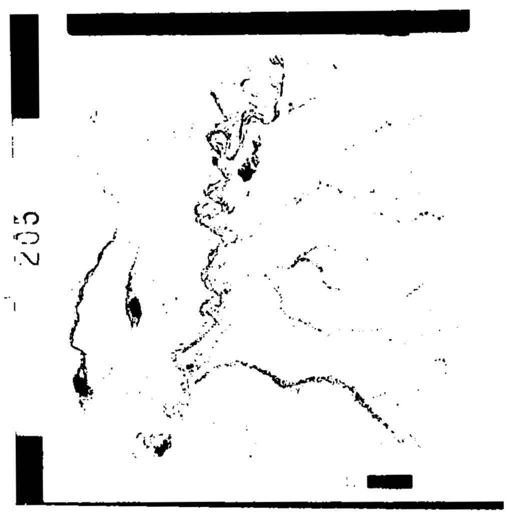
Figure 3.

FEB. 22, 1973

COMPOSITE OF 4,5,7

4

5



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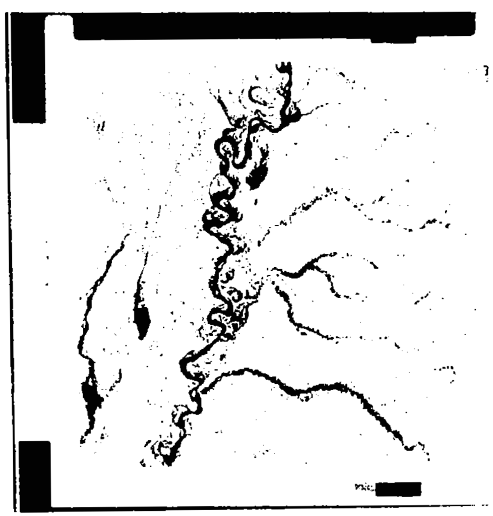

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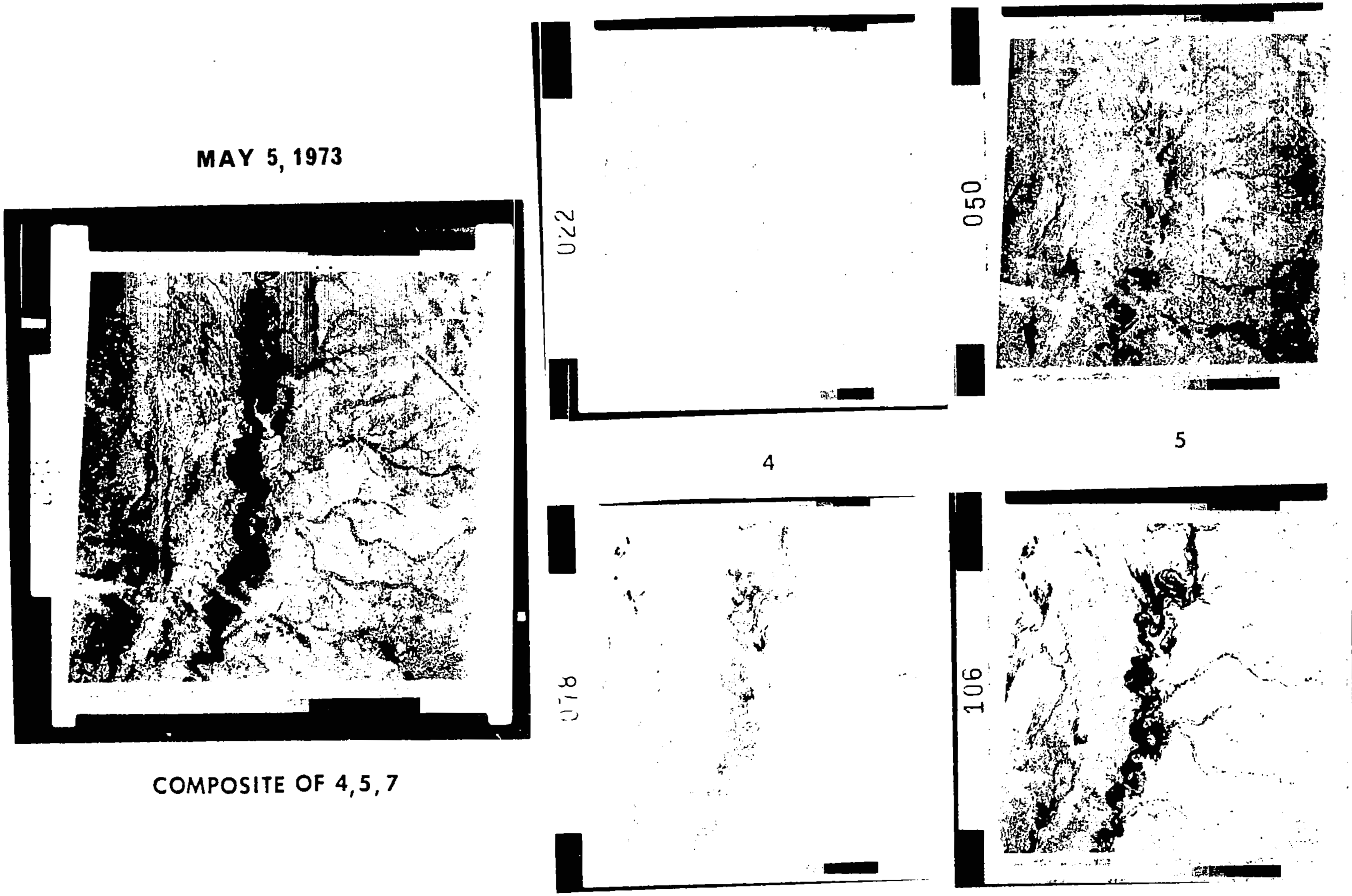
Figure 4.

MAY 5, 1973



COMPOSITE OF 4,5,7

4

5

6

7

Figure 5.

could be detected from multi-date Landsat bands 4, 5, 6, 7, and color composite imagery (Figures 3-5). The delineation of wetlands from remotely sensed data depends upon several criteria that are essential to the interpretation of any imagery:

1) tone - the distinguishable variations in shade from black to white

2) color - the property of an object which is related to the wavelength of the light it reflects

3) texture - the frequency of the change in tone and the arrangement of tones

4) pattern - the regularity and characterisitc placement of tones and textures

5) association - the combination and arrangement of the object(s) under consideration in reference to other related features

6) site - the location with respect to terrain features or other objects

7) shape

8) shadow

9) size

10) resolution - the degree of sharpness or clarity of an image

Tone and color are the primary indicies used to identify wetlands from the small scale multispectral, multiseasonal imagery. Wetlands exhibit a light gray to dark gray tonal signature on black and white (B&W) visible light bands 4 and 5, while they display a light gray to black tonal signature on B&W infrared (IR) bands 6 and 7. The difference in signature between wetlands and non-wetlands results from the better water absorption and vegetation detection capabilities of the infrared sensors in the Landsat MSS. Infrared radiation is absorbed more effectively by water than are visible light wavelengths; since water is a

primary component of wetlands, the tonal contrasts at the swampland fringes are more pronounced and easier to delineate on the IR imagery than on Landsat bands 4 and 5 data. Also, the forested wetland vegetation signatures are more distinct on the infrared bands than they are on the visible light band imagery.

One important drawback of B&W imagery, either visible or infrared, is that the human eye is not particularly sensitive to distinguishing between more than approximately 8 shades of gray values.[17] The dynamic aspect of color, therefore, is of utmost importance for the identification of discrete wetland variables from Landsat data. False color infrared or color composite imagery is by far the best type of imagery for visually delineating wetlands in West Tennessee. Color enhances the detectability of wetlands from the imagery because clarity is increased and fine details can be distinguished. For manual interpretation, it is much easier to perceive differences in color than changes in gray values.

The color range of wetlands (i.e., hue, value, and chroma) as displayed by the seasonal color composite data varies depending on the amount of water and foliage conditions present. Because of the infrared properties of Landsat color composite data, green wetland vegetation appears in various shades of red, bare soil is bluish-green, and water exhibits a blue to black tonal signature. The differentiation in colors, therefore, permits easier detection and delimitation of wetlands with greater detail from color composite imagery, particularly at the swampland interface with non-swamplands, in comparison with B&W imagery.

Texture, pattern, and association are also important indicies for detecting wetlands from Landsat imagery. Wetlands can visibly be sepa-

rated from non-wetlands on B&W scale imagery because of the smooth texture of the swamplands.

Pattern, the repetition or spatial arrangement of interpretational targets, is another visual guide for the identification of wetlands. Swamplands along the Obion, Forked Deer, and Hatchie Rivers display a sinuous pattern on the imagery. The repetition or arrangement of riverine wetlands is a dominant characteristic which can readily be distinguished.

Associated or related wetland phenomena are also helpful for the visual detection of wetlands from small scale Landsat imagery. Water is the primary associative index used to identify swamplands, since the presence of water is directly connected with the existence of swamplands.

The site or location of wetlands in West Tennessee is a correlative clue to their detection along with texture, pattern, and association. Wetlands occur in topographic lows; the Obion, Forked Deer, and Hatchie Rivers and the Mississippi floodplain are physiographic depressions which are capable of supporting wetlands. Specific topographic depressions, however, cannot be discerned on the imagery because Landsat data is small in scale and terrain relief is not distinguishable.

Shape and shadow are the two components of image interpretation which have the least utility in distinguishing wetlands from Landsat data. Wetlands conform to the physiography of the Obion, Forked Deer, and Hatchie River courses, but they have no particular shape in the Mississippi Lowlands. Agriculture and urban encroachment have made patchwork of the wetlands, particularly at the swampland fringes. Shadows created either by terrain or clouds are a hindrance to wetlands classification from Landsat imagery. At the time the imagery was

sensed, approximately 9:31 a.m. CST (15:31 GMT), terrain shadows from oblique angles of the morning sun were an obstruction to wetlands detection, especially in the heavily dissected eastern portion of the study area. The shadows obliterated detail and produced tonal signatures which were similar to wetlands.

Size and resolution are the most dynamic elements that influence the interpretation of wetlands from Landsat data. The size of the wetlands visible on the imagery is directly associated with the scale of the imagery used. Hence, it is more difficult to identify swamplands, particularly minute parcels of wetlands, at smaller scales than it is at larger scales because the wetlands appear smaller in size.

The minimum area that can be delimited on the Landsat data is also affected by the resolution of the imagery. Resolution is an extremely complex parameter of remote sensing, but it is generally defined as the ability of an imaging system (i.e. lens, filter, detector, emulsion, exposure, and processing) to record details that are distinguishable.

The resolution of any remotely sensed imagery is directly proportional to: 1) the brightness of the object to be resolved in contrast with the background against which it is imaged; 2) the aspect ratio, or ratio of the object length to the object width; 3) the object's regularity of shape; 4) the number of objects that comprise the pattern to be resolved; and 5) the background uniformity against which the object(s) are imaged. Furthermore, the resolution of any remotely sensed imagery is inversely proportional to: 1) the graininess of the film; 2) the amount of image motion in relation to the film at the instant of exposure; and 3) the amount of atmospheric haze between the camera lens or sensor system and the object.[18]

The clarity of detail or object detectability of Landsat data though, depends on acutance or edge sharpness as well as resolution.[19] Since the Landsat MSS is not a photographic sensor, but an electro-optical system, it is the contrast in illumination or the ability to show a sharp edge between objects that influences the detectability of wetlands from Landsat imagery. At 1:1,000,000 scale, the acutance of wetlands on the imagery is excellent and the edge sharpness is enhanced by the contrast in tonal signatures between wetlands and non-wetlands, particularly on the color composite imagery. The minimum wetland parcel size that can be discerned from the imagery, however, is related to the edge sharpness, resolution, and scale of the imagery. Although wetland parcels may have the same contrast attributes as larger tracts of swamplands within the study area, the small scale of the imagery along with the resolution properties of the MSS system limit the detection of small wetland parcels from 1:1,000,000 scale Landsat data. The interrelationship of wetlands detectability and measurability with resolution and size will be explained in the discussion of the Landsat verification procedures that have been developed for this study.

Classification of Wetlands from Landsat Imagery

As demonstrated by initial examinations of 1:1,000,000 scale satellite data, the wetlands of West Tennessee are photomorphic features that can be detected from small scale Landsat imagery. The mapping of wetlands from the data, however, requires more comprehensive information than just the identification of wetlands from Landsat. In order to map wetlands from the imagery, a wetlands definition or classification scheme must be developed that suits the user's needs and

is compatible with the multispectral, 1:1,000,000 scale Landsat data. Herein lies the most controversial aspect of swamplands mapping from remotely sensed data. What constitutes a wetland and what criteria should be used for classification?

It has been stated that:

> There is no single, correct, indisputable, ecologically sound definition for wetland because the gradation between totally dry and totally wet environments is continuous. Moreover, no two people view the identity of any object in the same fashion. For these reasons, and because the reasons for defining wetland vary, a great proliferation of definitions has arisen.[20]

The common denominator of all the wetlands definitions is the temporal presence of soil moisture in varying amounts. The conceptual framework of any wetlands definition, therefore, should embrace the relationship of water with soil, vegetative, and topographic features. The main disparity among definitions is not the question of water, but the question of how to categorize and delimit a wetland according to the associated characteristics that are a product of excess soil moisture. The brief survey of wetlands definitions which follows illustrates the applicability of several swampland classification schemes for mapping the wetlands of West Tennessee from Landsat data.

Wetlands Definitions

1. U. S. Soil Conservation Service

In 1975, an interdisciplinary committee of resource specialists from the U. S. Soil Conservation Service (SCS) adopted a wetlands definition for use in Tennessee that was based on soil moisture and vegetation conditions. A wetlands matrix was also developed to assist in the

classification of swamplands as dynamic, temporal, physical features. The SCS recommended that the Tennessee State Planning Office, Natural Resources Planning Section use the definition for any wetland planning activities within the state. Under the SCS definition an area may be classified as a wetland if the following conditions are satisfied:

1. Moisture Conditions

   a. Soils which have soil drainage classes of very poorly drained, poorly drained, and some areas of somewhat poorly drained or if soils data are not available, soils having water tables which are within 1.5 feet (46 cm) of the surface for six (6) months or more in most years, or

   b. Are permanently, temporarily, or intermittently covered with water, or

   c. Water on the surface of a duration long enough to sustain hydric vegetation.

2. Vegetation

   a. Hydric vegetation exists (i.e., vegetation that thrives on increased or excessive soil moisture conditions).

3. Size

   a. Contiguous area that is 2.5 acres (1 hectare) or more in size.[21]

The wetlands matrix that has been developed augments the SCS swamplands definition. The matrix classified wetlands on the basis of a temporal water regimen, vegetation, and soil moisture index system. Wetlands are defined in the matrix according to the type of vegetation and soils that exist within two broad water regimen classified as surface and internal water. The surface water regime is subdivided into a 12 month and two 6 month standing water categories. The second 6 month duration is a transitional time period of standing surface water which transgresses into the internal water regimen. The internal water regime

is also divided into 3 subcategories: 1) poorly drained, high water table; 2) well drained; and 3) excessively well drained. Additionally, soil moisture coefficients have been interfaced with the surface and internal water subcategories. The range of wetlands types extends from areas of standing water in excess of 12 months with submerged, rooted vegetation to poorly drained areas with a high water table that support swamp (shrub), marsh, cypress, or hardwood vegetation and have surplus moisture conditions.

Although the SCS definition and matrix provide an acceptable wetland classification scheme for most ground level or low to medium altitude surveys, an inventory of swamplands via Landsat imagery would be difficult using this system. It is not an optimum, efficient classification system for use with visually interpreted Landsat data because it requires detailed, temporal vegetation, water, and soil information to be effective.

2. USGS/TVA

The U. S. Geological Survey (USGS) and the Tennessee Valley Authority (TVA) have also developed a wetlands classification system for use in a cooperative West Tennessee swamplands mapping project. The swampland classification scheme is based on vegetation and frequency and duration of inundation. High altitude color infrared imagery is utilized as the primary data collection source. The USGS and TVA have defined wetlands according to two forested wetland classes and four non-forested wetland classes. These broad swampland classes have been divided into 12 subclasses; 5 forested wetlands and 7 non-forested wet-

lands. The USGS/TVA wetland classes and subclasses are outlined below:

I. Forested Wetlands (FW)

A. Bottomland Hardwoods (FW-1)

1. Upper Bottomland Hardwood (FW-1a)

2. Lower Bottomland Hardwood (FW-1b)

B. Swamp (FW-2)

1. Forested Swamp (FW-2a)

2. Shrub Swamp (FW-2b)

3. Dead Woody Swamp (FW-2c)

II. Non-forested Wetlands (M)

A. Marsh (M-1)

1. Wet Meadow (M-1a)

2. Emergent Marsh (M-1b)

3. Seasonally Emergent Marsh (M-1c)

B. Seasonally Dewatered Flats (M-2)

1. Seasonally Dewatered Flats Vegetated (M-2a)

2. Seasonally Dewatered Flats Non-vegetated (M-2b)

C. Agriculture Subject to Flooding (M-3)

D. Open Water (OW-1)

1. Vegetated Open Water (OW-1a)

2. Non-vegetated Open Water (OW-1b)

The USGS/TVA wetlands definition also gives more specific vegetation and hydrologic characteristics with each class and subclass; e.g., "Bottomland Hardwood (FW-1): Wetland dominated by mixed hardwood species and flooded annually during winter or early spring. Flooding may be brief or for long periods. The ground is usually exposed in summer and

fall although soil may be saturated or covered locally with a few inches of surface water."[8]

The wetlands classification scheme prepared by the USGS/TVA cooperative effort has been utilized to map four test sites in West Tennessee from high altitude (1:130,000 scale) aircraft photography. The wetlands have been mapped at a 1:24,000 map scale to facilitate the mapping of small wetland tracts and to correlate the wetland classes with 1:24,000 scale USGS topographic maps. The results of the wetlands classification and mapping project indicate that the aerial photography provides detail to map wetlands as small as 1.06 acres (.43 hectares) in size and 65.6 feet (20 meters) in width.[8]

The USGS/TVA swamplands classification system, unlike the SCS definition, is designed to obtain the optimum blend of interpretable and mappable swampland information from the primary data source; that is the high altitude color infrared aircraft photography. The USGS/TVA wetlands classification system in its entire form, however, is not applicable for mapping wetlands from Landsat data for several reasons: 1) the system is designed for use with a high altitude aerial photographic information base; 2) the data collection procedure requires that wetland class and subclass information provide sufficient detail for mapping at 1:24,000 scale; and 3) the classification system requires specific, temporal data on vegetation and frequency and duration of inundations to be fully operational. Points 1 and 2 limit the utility of the USGS/TVA classification system for swampland identification and mapping from Landsat data. Since Landsat is recorded at a very small scale, the delineation of the USGS/TVA wetland classes and subclasses developed for 1:24,000 scale mapping would be restricted from the satellite imagery, even with

the aid of image enhancement, scale enlargement, and mechanical interpretation techniques.

Another drawback to using the USGS/TVA system for wetlands mapping from Landsat imagery is the need for temporal vegetation and hydrologic data to support the classification scheme. At the scale of Landsat, the 6 primary wetland classes in the USGS/TVA system are broad enough to be useful for wetlands mapping, but the feasibility of obtaining the additional data to support the forested and non-forested swampland classes on a continual basis is questionable. Also, a slight, gradual change in the wetlands water regime and vegetational composition may have a substantial impact on the interpretability of the wetlands classes from Landsat data. The swampland continuum between permanently wet and dry is so dynamic that it would be difficult to use the USGS/TVA classification system for mapping wetlands from Landsat data.

Although the SCS and USGS/TVA wetlands definitions and classification systems have been designed for application in West Tennessee, they are not the most effective classification systems for use with Landsat imagery. The SCS and USGS/TVA systems are too detailed for mapping at the scale of the Landsat data and require specific, temporal, corraborative information to be fully operational. A wetlands definition and classification that can be applied to Landsat imagery must be broad in scope. The small scale of the imgery must be taken into consideration when adopting a wetlands classification system; if more detailed information is required to satisfy the users needs, the data should be collected from an alternate data source.

3. U. S. Fish and Wildlife Service

The U. S. Fish and Wildlife Service (FWS), Office of Biological Services has prepared a wetlands definition that is broad enough to be useful for mapping wetlands from Landsat imagery. The definition is part of a comprehensive classification program designed for use in the National Wetlands Inventory. The FWS defines wetlands as ". . . land where the water table is at, near or above the land surface long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental conditions are favorable . . . Wetlands lacking vegetation and hydric soils can be recognized by the presence of surface water at sometime during the year and their location within, or adjacent to vegetated wetlands or aquatic habitats."[20]

The FWS definition is similar to the definition used by the SCS, but requires less specific soils data and has no restrictions on size. In the FWS definition two basic elements must be present for an area to be classified as a wetland; 1) hydrophytic vegetation (i.e., vegetation types capable of growing in soil that is at least periodically deficient in oxygen as a result of excessive water content), and 2) detectable surface water. Wetland vegetation, whether woody or aquatic, is identifiable on the Landsat imagery since wetlands vegetation exhibits a unique tonal signature; standing water is also detectable from Landsat.

The Interim National Wetlands Classification System that accompanies the FWS wetlands definition is comprehensive and includes the entire spectrum of wetland ecosystems from general to specific. The FWS classification system is hierarchically arranged as follows:[20]

I. Provinces (e.g. Californian Province, Carolinian Province)

   A. Ecological Systems (i.e., Riverine, Lacustrine, Marine, Estuarine, and Palustrine)

      1. Ecological Subsystems (e.g. Riverine System - high and low gradient reach, and tidal reach)

         a. Habitat class (e.g. Forested, Shrub Emergent Wetlands)

            1. Habitat Subclass

               aa. Orders

                  1a. Habitat type (formed by adding modifiers for water regime and water chemistry to the order).

The design of the FWS system permits wetlands to be classified uniformly for the entire U. S. at multiscaled levels. Wetlands can systematically be classified from Landsat data depending on the type of swampland features that are detectable on the imagery. The FWS system does not confine itself in scope, but it is restricted only by the interpretative limits of the data source used.

The FWS classification scheme, however, is an interim system that is subject to field evaluation and revision. Also, at the scale of the Landsat imagery (1:1,000,000) used in the study, the FWS classification is applicable only at the broadest levels. Wetlands are distinct photomorphic features that can be detected on the small scale imagery, but it is doubtful that swampland habitat types other than forested wetlands in the FWS system can visually be discriminated on the imagery. Although the FWS system can be used to classify wetlands from small scale Landsat data,

the National Wetlands Inventory intends to employ the system in mapping swamplands for the entire U. S. at 1:250,000 scale or larger; hence, the optimum level of operation for the system is at scales much larger than 1:1,000,000.

4. The USGS Land Use and Land Cover Classification System

Of the three wetlands classification schemes discussed so far, the FWS system is the best suited for mapping swamplands from Landsat imagery. The FWS wetlands definition is broad enough to be utilized with Landsat data, and the versatility of the FWS classification system allows for the discrimination of wetland ecosystems at various scales. For the mapping of West Tennessee wetlands from visually interpreted Landsat imagery in this study, however, the most functional classification scheme is the system prepared by Anderson, Hardy, Roach, and Witmer of the USGS. The USGS system is a multi-level land use and land cover classification system for use with remote sensor data.[22] The system has been developed to meet the needs of federal, state, and local agencies for a broad overview of national land use and land cover patterns and trends. Level I categories are designed for use with 1:1,000,000 to 1:250,000 scale Landsat imagery; Level II categories are used with 1:250,000 to 1:24,000 scale imagery interfaced with topographic maps. Land use classification Levels III and IV are utilized with medium altitude (1:80,000 to 1:20,000 scale) and low altitude (larger than 1:20,000 scale) imagery. The system is not restricted to scale, however, and Level II, III, and IV categories can be mapped from Landsat data if they are discernable on the imagery. Conversely, Level I cate-

gories can be mapped from large scale aerial photography if a general land use classification is desired.

Wetlands are classified as a Level I land use and land cover category in the USGS system. The definition of wetlands is similar to the one used in the FWS system; generally, "Wetlands are those areas where the water table is at, near or above, the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation usually is established, although alluvial and tidal flats may be nonvegetated."[22] The USGS Land Use System also establishes that vegetation and detectable surface water or soil moisture are the most appropriate means for identifying wetlands and wetland boundaries from Landsat imagery. Level I wetlands, therefore, can be identified and delimited from Landsat data with little or no supplemental information.

At Level II, wetlands are subdivided into forested and non-forested categories. The Level II wetland categories, if detectable on the imagery, are classified according to the dominant vegetation or lack of vegetation present. Forested wetlands are dominated by woody vegetation and include seasonally flooded bottomland hardwoods, shrub swamps, and wooded swamps. Non-forested wetlands are dominated by herbaceous swampland vegetation or are non-vegetated. Wetlands as detected from the 1:1,000,000 scale Landsat data in this study are best classified at Level I, since non-forested wetlands cannot effectively be discriminated from forested wetlands using visual techniques.

For mapping wetlands in West Tennessee from Landsat data, the USGS system provides a functional guideline for wetlands definition and

classification. The system is easy to use, does not attempt to extract information that is beyond the limits of the data source, and gives uniform results that can be integrated with a national land use and land cover classification project. Hence, the USGS system at Level I is the optimum classification scheme that can be used to visually map the wetlands of West Tennessee from 1:1,000,000 scale Landsat data.

Monitoring Inter-image and Intra-image Wetland Dynamics from Multispectral/Multiseasonal Landsat Imagery

The USGS Land Use and Land Cover Classification System was used to map the wetlands of West Tennessee from three dates of multiband Landsat imagery (Appendix A, Maps 3-17). As indicated by the maps of the September, February, and May imagery, the wetlands change significantly in size and in standing water content from season to season.
The September 13, 1972 image maps 3-7 in Appendix A depict the wetlands at the foliated, low water stage. The wetlands were mapped primarily on the basis of vegetation tonal signatures, since standing water was minimal at the time the imagery was sensed (Figure 3). Maps 8-12 in Appendix A illustrate the wetlands as interpreted from the February 22, 1973 multiband Landsat data (Figure 4). This date represents the wetlands in mid-winter when vegetation is dormant and surface water is detectable throughout the swamplands. Lastly, the May 5, 1973 image maps 13-17 in Appendix A illustrate how the wetlands were interpreted from the multispectral Landsat imagery (Figure 5) at the early foliated, spring flood stage. At the time the imagery was sensed, streamflow in the Mississippi-Missouri River basins reached the highest flood levels since

1844 in some locations, and much of the Mississippi, Obion, Forked Deer, and Hatchie River lowlands were inundated.

As the maps of the multispectral imagery illustrate, Landsat is an excellent medium for detecting seasonal wetland dynamics in West Tennessee. The monitoring of inter-image, temporal changes, however, was not the only reason for mapping swamplands from Landsat. Of considerable importance to the Landsat mapping procedure was the study of the intra-image wetland changes that took place as a result of the different spectral characteristics of each band within the same image. The Landsat maps show that the interpretability of wetlands differs from band to band for the three dates of imagery used in the study. The B&W infrared bands, because of their spectral characteristics which accentuate water and areas of increased soil moisture, exhibit a greater contrast between wetland and non-wetland tonal signatures in comparison with the B&W visible light band imagery. The better mapping properties of the infrared imagery are substantiated by the amount of wetlands detail that was mapped from bands 6 and 8 of the September, February, and May Landsat imagery.

The optimum Landsat imagery for mapping wetlands, however, is the color composite data. Color variations are more easity detected than are changes in gray tones on the Landsat data. Also, details of wetland surfaces are more readily seen on the color composite imagery in comparison with the B&W bands. This decreases eye strain and increases mapping efficiency.

PROBLEMS ENCOUNTERED IN THE LANDSAT MULTISPECTRAL IMAGERY WETLANDS MAPPING PROCEDURE

Although the mapping procedure was uncomplicated, there were several areas on the imagery that were difficult to map. Wetlands were troublesome to delineate on the imagery in three areas: 1) at the upper reaches and tributaries of the Obion, Forked Deer, and Hatchie Rivers; 2) within the Mississippi Lowlands; and 3) around urban areas. The cartographic problems encountered in these areas were primarily related to seasonal changes in the wetlands milieu.

At the upper reaches of the Obion, Forked Deer, and Hatchie Rivers (Map 2), the topography is rolling and heavily dissected, and much of the land is forested. The wetlands in the eastern portion of the study area become narrow and begin to branch out as they approach the headwaters of the rivers. Since there is less wetland area to be detected, the upper reaches of the swamplands merge with upland vegetation and are difficult to map. Furthermore, tributary wetlands are small in size and their tonal signatures intermix with cropland or forested upland signatures. On imagery taken during the winter (defoliated) season, the wetlands at the upper reaches are much easier to map since the swamplands display darker tones under the tree canopies; the tonal signature contrast is greater, therefore, between wetlands and non-wetlands.

The wetlands within the Mississippi Lowlands are a problem to map because of their small size. Although a few large wetland areas exist within the Lowlands, agricultural operations have divided most of the

swamplands into extremely small parcels which are difficult to delineate on the small scale imagery.

It is also a problem to identify and delimit wetlands around urban areas on the Landsat imagery. Wetlands which meet built-up areas are fractured by urban encroachment. The wetland tonal signatures intermix with the urban signatures and the two areas become visually inseparable. The built-up areas around Jackson, Tennessee, on the South Fork and Dyersburg, Tennessee, on the North Fork of the Forked Deer River, however, are the only areas where the wetland versus urban signature problem is acute.

Although interpretation difficulties hinder the Landsat mapping procedure, they do not vitiate Landsat imagery as a medium for mapping wetlands in West Tennessee. The impact of these problems on the mapping procedure is mitigated considerably when the size of the wetland areas involved is compared with the entire wetland area that has been mapped in West Tennessee. Moreover, the Landsat data base used in this study is comprised of only three dates of imagery, so the problems encountered in delimiting wetlands could either be alleviated or eliminated when other dates of satellite imagery are used for interpretation.

LANDSAT MAPPING PROCEDURE: SUMMARY

The Landsat mapping procedure has demonstrated that wetlands in West Tennessee could be identified and delimited from 1:1,000,000 scale Landsat imagery. The ability to discern wetlands, however, depends on the interrelationship and variability of several photo-interpretation indicies. Tone and color are the primary factors that are used to

visually detect wetlands from Landsat imagery; swamplands exhibit a unique tonal signature which is a key to their identification. Texture, pattern, association, shape, and shadow, are ancillary parameters that aid in the detection of wetlands from Landsat data. The minimum size of the wetlands identifiable on the imagery is affected by the resolution, edge sharpness, and scale of the data. The amount of detail evident on the Landsat data is a variable of the MSS system and the small scale at which the imagery is sensed.

Although wetlands as photomorphic features were identifiable on the Landsat imagery, the swamplands had to be defined according to a classification scheme that was compatible with the scale of the data, and one that was acceptable to the users of the cartographic information. The USGS Land Use and Land Cover Classification System, therefore, was used to classify and map wetlands in West Tennessee from Landsat data. Wetlands were best defined at the Level I category, since this division of the multi-level system was designed for use with 1:1,000,000 to 1:250,000 scale Landsat imagery.

The swampland maps generated from the September, February, and May imagery illustrate the capabilities of Landsat data for monitoring seasonal wetland dynamics within the study area. Maps 3-17 in Appendix A also show that wetlands detail varies considerably according to the visual characteristics of the multispectral imagery. In a comparative analysis of the Landsat multispectral data, the most useful type of information for mapping wetlands at 1:1,000,000 scale was the color composite imagery. The mapping of wetlands from the three dates of

multispectral Landsat data involved photo-interpretational and cartographic difficulties, but these were minor in scope and impact.

The results of the Landsat wetlands mapping procedure are encouraging. Landsat is an excellent medium for visually identifying and mapping wetlands in West Tennessee. Resource-oriented agencies interested in wetlands, however, need areal measurement data for swamplands management as well as cartographic information. Wetland inventories must be up-dated periodically to be of maximum utility, and the acquisition of data via aerial photography on a frequent, regular basis is economically unattractive. The accuracy of Landsat imagery for wetlands mapping and measurement, therefore, will be examined in the remainder of the study.

CHAPTER III

LANDSAT VERIFICATION PROCEDURE - PART I

The Landsat verification procedure that has been developed for the study is presented in two stages. Part I deals with the selection of a Landsat imagery data base, the comparison of the imagery with U. S. National Map Accuracy Standards, the location and mapping of 14 transects as case study areas, and the computation of the scales of medium altitude photo frames used as control parameters. Part II of the verification procedure, discussed in Chapter IV, is concerned with the implementation and results of the accuracy tests and the overall measurement of the West Tennessee wetlands from Landsat imagery.

Selection of a Landsat Imagery Data Base for the Study

Since the Landsat verification procedure was designed to evaluate the comparative accuracy of 1:1,000,000, 1:500,000, and 1:250,000 scale data for mapping and measuring wetlands, a single scene of multispectral satellite imagery was utilized in the study. The September 13, 1972 color composite imagery was selected as a Landsat data base because the wetlands could easily be identified by their distinctive deep red color. The imagery also depicted the wetlands at the low water stage; hence, if the wetlands could be demarcated at low water, then seasonally related swamplands could be detected at higher water periods.

Evaluation of Landsat Imagery in Relation to NMAS

To test the reliability of Landsat data as a medium for mapping and measuring wetlands, it was first necessary to analyze the planimetric characteristics of the imagery in reference to recognized map standards. The imagery was compared with the United States National Map Accuracy Standards (NMAS) established for thematic maps at publication scale. For acceptable planimetric accuracy, NMAS require that 90 percent of the "well defined features on the map, should be in error by no greater than 0.02 inch (0.5 mm) measured at the scale of publication."[19] This measurement on the ground represents 1640 feet (500 m) at 1:1,000,000 scale, 820 feet (250 m) at 1:500,000 scale, and 410 feet (125 m) at 1:250,000 scale. Since positional map errors are not normally distributed, the root-mean-square error (rms) of the points should be less than 984 feet (300 m) at 1:1,000,000 scale, 492 feet (150 m) at 1:500,000 scale, and 246 feet (75 m) at 1:250,000 scale to satisfy NMAS requirements (Appendix B - 48).[19]

The geometric properties inherent in the spacecraft's MSS present a problem in calculating the root-mean-square error for points on Landsat data; Landsat imagery represents a photomap that has been superimposed upon an unknown projection and the positional data for each point, therefore, are ambiguous.[24] One recognized way to transform Landsat imagery into an accurate photomap for comparison with NMAS is to make the best fit of a geodetic grid, such as the Universal Transverse Mercator (UTM) or latitude and longitude system, to bulk MSS imagery via ground control. The positional error for ground control points is then computed according to their distance from the nearest grid line.

Root-mean-square tests of ground control points from imagery fitted with a UTM grid have yielded results that meet NMAS for maps at publication scale.[19]

The procedure for fitting a UTM grid to an image requires four basic processes: 1) identification of control points and recording their specific ground coordinates; 2) measurement of the x and y point values on the image; 3) calculation of the transformation parameters which relate the image and ground coordinate systems; and 4) plotting of the UTM grid on an overlay sheet that is precisely registered to the image.[24]

This grid-fitting procedure would normally require a computer program and a digitizer for calculating the transformation parameters, and for relating the grid intersections to the image coordinate system. In lieu of the equipment necessary to digitize the data points, a simpler grid-fitting technique was used. The method developed for the study relied on manual operations and surrogate information to make the best fit of an overlay sheet with the September 13, 1972 color composite imagery.

Twenty control points were pin-pricked on the bulk-processed Landsat 1:1,000,000 scale imagery. No more than twenty points were identified so that isolated mispricked points could be corrected or eliminated. Corners of woodlots, river and stream confluences, lakes, and highway crossings were the primary sites used to locate suitable ground control points on the imagery.

The same twenty points were then identified and marked on an overlay of a Landsat precision-processed image of West Tennessee study area

(ID# E-1070-16055-4,5,6,7-1, October 1, 1972). The precision-proc imagery was used for calibration control since the image was geome- -cally corrected in reference to a UTM grid by NASA. It was necessary to carefully register the ground control points on the overlay sheet with the precision-processed imagery to assure that the location of the pin-pricks coincided with the same points on the bulk imagery. Although care was taken in pricking the control points on the overlay, slight aberrations in marking the points were inevitable. These errors, however, were either ignored or were compensated for in the grid-fitting procedure.

After the ground control points were pricked on the overlay, a best-fit of the overlay with the bulk imagery was accomplished by selecting two or more pin-pricks on the September MSS data and matching these points with the same points on the precision-processed sheet. This alignment procedure was performed six times with different points to determine the rotation parameters necessary to compute a plane-to-plane adjustment of the imagery with the UTM grid. A single plane rotation was used since the precision-processed overlay was manually rotated over the bulk imagery.

When the calibration points were registered, the displacement between each point on the bulk imagery and precision-processed overlay was measured using a hand-held mono-comparator. The comparator was equipped with a 15 mm linear scale, and measurement was made to the nearest 0.1 mm. After the position for each point was tabulated, the rms for all of the points was calculated and compared with NMAS.

The results from this overlay operation indicated that at the 1:1,000,000 scale, Landsat imagery closely approached NMAS when the rms

was calculated using the displacement measurements for all twenty test points (Table I). However, when the two point alignment fits which produced the smallest rms aberrations were averaged together, their rms was approximately 30 meters greater than NMAS allow at 1:1,000,000 scale. The mean rms of the two lowest rms errors, therefore, was a surrogate for the best-line-of-fit that could have been achieved. NMAS also state that 90 percent of the test points should be in error by

TABLE I

RMS OF 90% OF POINTS TESTED

1:1,000,000 IMAGERY

TEST 1	TEST 2	TEST 3	TEST 4	TEST 5
rms = 360 m	rms = 310 m	rms = 440 m	rms = 310 m	rms = 300 m

no greater than 0.2 inch (0.5 mm) at the scale of publication. Hence, if the two largest point positional errors were eliminated when the mean of the two best alignment fits was computed, NMAS would be achieved at 1:1,000,000 scale using 90 percent of the points. Because the results in Table I were obtained by performing a manual alignment fit of ground control points, it was assumed that NMAS could be attained using computerized techniques at 1:1,000,000 scale for the September 13, 1972 Landsat imagery. Furthermore, based on the results from the rms testing of the Landsat 1:1,000,000 scale imagery, it was hypothesized that NMAS would be approached or met at scales of 1:500,000 and 1:250,000 if the two largest

positional errors were dropped and the rms was based on the mean of the two best-point alignment fits.

Transect Site Location and Mapping

The results of the rms tests indicated that the September 13, 1972, imagery used as a data base for the Landsat verification procedure was a cartographically accurate photomap; the internal geometry of the imagery was within the standards prescribed for maps at publication scale. Any errors in the visual measuring and mapping of wetlands from the imagery, therefore, could be attributed to factors other than geometric and planimetric aberrations within the Landsat imagery.

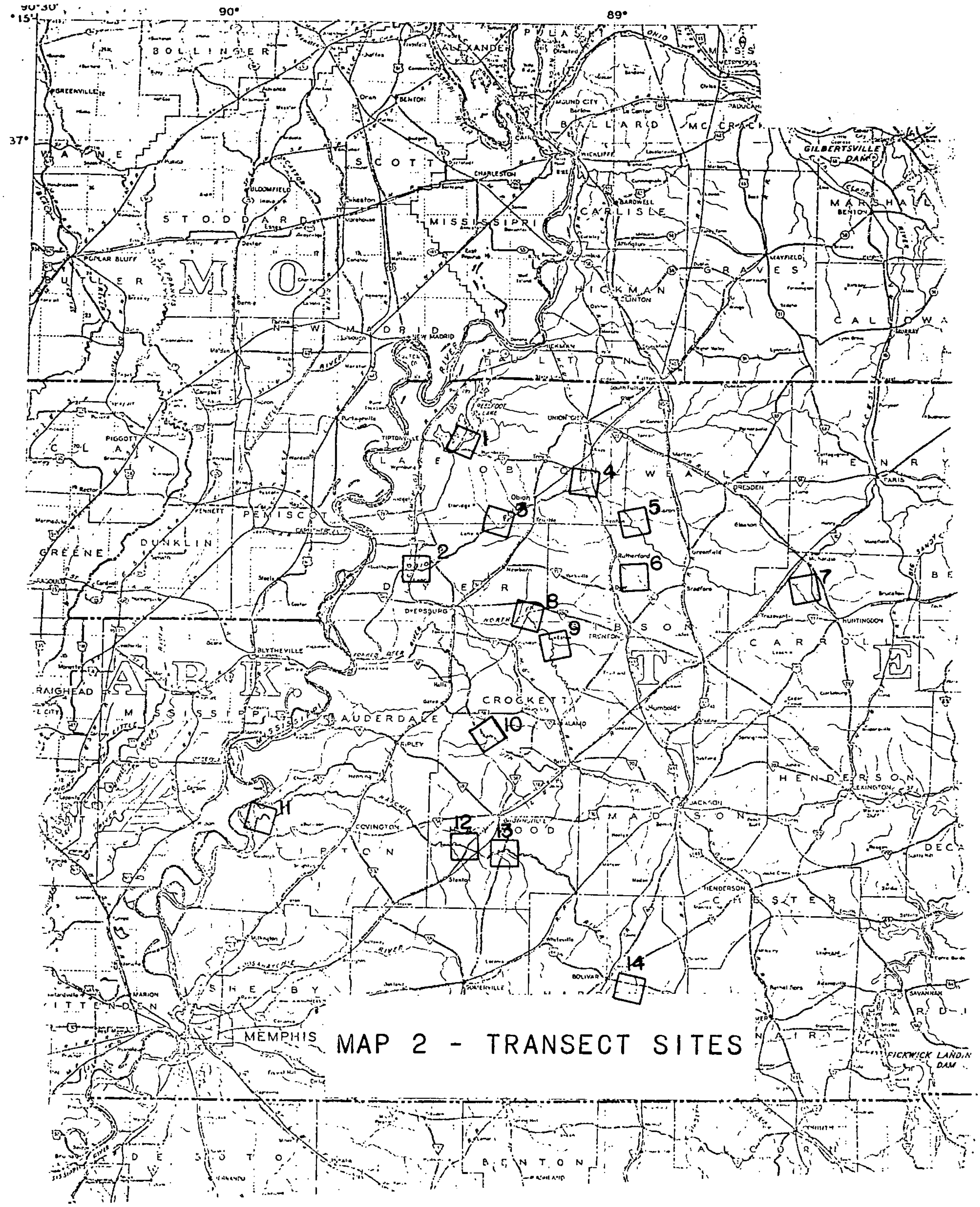
The NMAS tests laid the foundation for the Landsat accuracy testing procedure. This procedure was predicated on information obtained from medium altitude, color aerial photography taken of the West Tennessee wetlands. The color infrared aircraft imagery, flown by NASA on April 23 and 24, 1974, was used as ground truth data for comparison with the Landsat September 13, 1972 color composite imagery. Fourteen transect sites or case study areas were selected from individual 9 x 9 inch (23 x 23 cm) photo frames on the aerial photography (Map 2). The same transect sites were also located on the September Landsat imagery information base. These case study areas were utilized for control calibrations to assess the cartographic accuracy of the Landsat imagery.

The transect sites were chosen because they displayed photomorphic characteristics that were detectable on the Landsat and aircraft imagery. Physical and cultural features, such as river and stream confluences, lakes and borrow pits, interstate or major highways, and unique patterns of wetlands encroachment or land uses, were utilized to locate

the transect sites. Additionally, the case study areas were distributed so that all 14 transects provided a representative view of the West Tennessee wetlands.

After the case study areas were identified on the Landsat and medium altitude imagery, the land cover in each transect photo frame was mapped using a modified version of the USGS Land Use and Land Cover Classification System (Appendix C, Maps 19-33). The wetlands within each transect photo frame were mapped at Level II, although wetland related features which aided in the visual interpretation of swamplands from the imagery were also classified. Additionally, land cover other than wetlands was mapped from the photo frames for orientation of the transect sites within the study area, and for illustration of the various types of land uses that surround the West Tennessee wetlands. Forested and non-forested wetlands were delimited on the basis of several factors: 1) topography; 2) the presence of water; 3) the existence of wetland related features such as dead timber; and 4) the tonal signature of the trees present.

Topography is the key factor used to map wetlands from the medium altitude photo frames. It is apparent from field surveys and from the examination of USGS, 1:24,000 scale topographic maps that wetlands within West Tennessee are associated with topographic lows: generally the appearance of wetlands coincides with datums below the 300 foot (92 m) contour level. This contour, however, is not an absolute determinant of the upper wetland datum since the map contours may be aberrant by several feet. Also, the elevation of the wetlands is higher in the heavily dissected eastern and southern portions of the study area.


MAP 2 - TRANSECT SITES

The presence of water is another physical element used to map swamplands from the aerial photography. One primary characteristic of inland wetlands is a water table that is raised near or above the ground surface for a significant portion of the year. Swamplands, therefore, are associated with areas of increased soil moisture, or where water is present. The existence of water, however, is temporally related and should not be used as the sole determinant in the classification of wetlands. Because seasonal or short-term flooding may be an integral factor in the total annual soil moisture necessary for crop production, saturated agricultural lands have not been classified as wetlands, but they have been mapped from the imagery.

Additionally, wetland-related features such as dead timber and marshlands have been used to map swamplands from the aerial photography. Timber kill is widespread throughout the wetlands study area, particularly in the Obion and Forked Deer River basins. Marshlands, those areas dominated by hydrophytic or aquatic vegetation floating on water, are unique to a wetland milieu and are discrete features for swampland identification and mapping.

The type of forest cover and tonal signatures of the woody vegetation are definitive elements used to delimit wetlands from the aircraft imagery. Deciduous forest swampland vegetation exhibits a deeper red tonal signature than do the upland woodlands on the imagery. The tonal signature differentiation between wetland and non-wetland forested vegetation, however, is subtle in places. This is particularly true in the eastern and southern portions of the study area where the upland forest is dense and the terrain is heavily dissected; the uplands display a tonal signature which is similar to that of the forested uplands.

The wetland environment, therefore, is comprised of a complex ecosystem and the photomorphic features used to map swamplands from the aircraft imagery are interrelated. Hence, the key to the delimitation of wetlands from the medium altitude photography is the association of topographic, moisture, and vegetational parameters that distinguish wetlands from non-wetlands.

Computation of Medium Altitude Photo Frame Scale

Once the wetlands within each transect site were mapped from the medium altitude imagery, it was necessary to compute the scales of the 14 photo frames used as ground control for the Landsat comparative accuracy tests. Only the photo scale of the wetlands area within the transects was required, since the goal of the study was to verify Landsat as a medium for mapping and measuring swamplands in West Tennessee. The scale of the aircraft imagery was determined by calculating the average photo scale of the wetlands within the individual photo frame. This method was used because it was desirable to reduce the effect of terrain differences on the scale of each photo frame as much as possible. The vertical relief within the transect sites located in the western portion of the wetland research area is generally minimal, while it is highly variable in the eastern and southern sections. The effect of terrain differences on scale then, could most efficiently be minimized by computing the average photo scale of the wetlands within each photo frame (Appendix B - 56).

Although the average photo scale method reduced the influence of terrain variation on the scale of the photography, it was still necessary to define the maximum and minimum wetland elevations for each

transect. The wetland datum levels were determined by estimating how far wetland photomorphic features on the transect photo frames, such as tonal signature, extended in relation to topographic contour intervals on 1:24,000 scale topographic maps. The scales of the 14 photographs used as ground truth in the study are given in Table II.

Landsat Verification Procedure Part I: Summary

Part I of the Landsat verification procedure laid the groundwork for the wetland accuracy testing analysis. The September 13, 1972, color composite MSS imagery was selected as a Landsat data base for the study. This imagery was compared with U. S. National Map Accuracy Standards via an overlay of a geometrically corrected point data coordinate system to evaluate the planimetric accuracy of the imagery. The results of the NMAS tests illustrated that at 1:1,000,000 scale, the September imagery approached or met NMAS established for thematic maps at publication scale. It was inferred from the NMAS tests that the 1:500,000 and 1:250,000 scale Landsat data used in the verification procedure would also approach or meet NMAS.

The NMAS tests indicated that the September 13, 1972, imagery was an accurate photomap. Fourteen transect sites were then selected and mapped from individual 9 x 9 inch (23 x 23 cm) photo frames on the color infrared aerial photography that was used as ground truth data; the same transect sites were also located on the Landsat imagery. Lastly, the average photo scale of the wetlands within each photo frame transect was computed to facilitate the measurement of the swamplands from the case study areas for comparison with the three scales of Landsat data utilized in the accuracy testing procedures.

TABLE II

Location and Scale of Photo Frames Used as Ground Truth

For the Study's 14 Transect Sites

(See Appendix C, Maps 18-32)

TRANSECT #	LOCATION	SCALE
1	Reelfoot Lake at Samburg, Tennessee	1:25,425
2	Obion River at Confluence with Running Reelfoot Bayou	1:25,465
3	Lower Obion River Southwest of Obion, Tennessee	1:25,445
4	Confluence of the North and South Forks, Obion River	1:25,420
5	Confluence of the Middle and South Forks, Obion River	1:25,410
6	Rutherford Fork, Obion River near Dyer, Tennessee	1:25,340
7	Confluence of Crooked and Clear Creeks with South Fork, Obion River	1:25,270
8	Confluence of Middle and North Forks of Forked Deer River	1:25,440
9	Middle Fork of the Forked Deer River at Confluence with Buck Creek	1:25,435
10	Confluence of Nixon Creek with the South Fork of the Forked Deer River	1:25,435
11	Confluence of the Hatchie and Mississippi Rivers	1:25,535
12	Hatchie River at U. S. 79	1:25,425
13	Hatchie River at I-40 and S. R. 76	1:25,414
14	Hatchie River at Porter Creek Canal	1:25,290

CHAPTER IV

LANDSAT VERIFICATION PROCEDURE - PART II

In this chapter, the details and results of the Landsat verification analysis are described. The procedure was based on the areal and linear measurement of wetlands within 14 transect sites selected from medium altitude, color infrared aerial photography of the West Tennessee study area. The results of each measurement were compared with areal and linear measurements of the same area on Landsat 1:250,000, 1:500,000, and 1:1,000,000 scale imagery. The most accurate or reliable scale of Landsat imagery as determined by the verification testing was then used in an overall measurement of the wetlands along the Obion, Forked Deer, and Hatchie Rivers.

Calculation of Transect Wetland Area from the Medium Altitude Photo Frames

Part of the Landsat verification procedure was the measurement of wetlands within the 14 transect photo frames. The calculation of the photo frame areas was based on the individual scale of the transects as computed via the average photo scale method outlined in Chapter III. One transect, a section of the Rutherford Fork of the Obion River wetlands east of Dyersburg in Gibson County, Tennessee, was chosen as a test site for evaluating the efficiency and reliability of several techniques used to measure area (Appendix C, Map 23, Transect #6). This

site was selected because the swamplands within the transect were small enough to be measured easily using a polar planimeter. The areal figures obtained from the polar planimeter measurements were utilized as a calibration gauge for comparison with measurements of the same test site acquired from a dot planimeter, an area grid (10-to-the-inch cell grid), and a modified acreage grid.

The polar planimeter is a standard area measurement instrument that can be used to estimate the size of irregularly shaped units.[25] Area is computed by tracing the boundaries of the unit in a clockwise direction with the arm of the planimeter. The unit area is then read off on the instrument's vernier wheel and converted into the unit of measurement desired (e.g. feet/meters or acres/hectares). Although the polar planimeter can yield accurate measurements if used carefully, the slightest error in operation will produce significant aberrations in the area readings. Polar planimeters are also tedious and time consuming to use. When measuring a large number of areas, therefore, it is much easier to utilize more time-efficient methods and use the polar planimeter to check the accuracy of the other area measurement tools.[25] A total of 886.46 acres (358.75 hectares) of wetlands were measured from the test site using the polar planimeter.

The dot planimeter is a statistical sampling instrument used to compute the dimensions of an area (Figure 6). A dot planimeter consists of a transparent grid that is partitioned into square spaces with dots systematically arranged in each space. The size of the spaces and the density of the dots depends on the percentage of sampling needed. Dots

located within the boundaries of the area measured are counted and assigned a certain value depending upon the scale of the area measured and the spacing of the dots. Computation of area is then determined by simple proportion. Dot planimeters give area dimensions of acceptable accuracy in one-third to one-sixth of the time required for measuring the same area by a polar planimeter.[18]

The dot planimeter used in this study had 400 dots (9 dots/sq. inch or 1.4 dots/sq. cm) with each dot equivalent to 14.50 acres (5.87 hectares) at the scale of the test site photo frame. To obtain a reliable sample, the dot planimeter was dropped on the test site 10 times, and the mean number of dots counted for each planimeter fall was used to compute the total wetland area. An aggregate of 885.88 acres (358.51 hectares) of wetlands were measured within the test area via the dot planimeter. The difference in swampland area measured between the polar planimeter and the dot planimeter was -1.58 acres (-.24 hectares).

Another instrument used to measure the wetland area in the test site was the area grid or 10-to-the-inch cell grid (Figure 7). The transparent grid utilized in this study was comprised of a series of 1 inch (2.54 cm) squares that were subdivided into .10 inch (.25 cm) square cells. The area grid was placed over the transect site and a visual estimate was made of the proportional amount of wetlands area in each cell of the grid. There were 872.11 acres (352.94 hectares) of swamplands recorded from the 10-to-the-inch cell grid measurement of the test site; the difference between the grid and the polar planimeter was -14.35 acres (-5.82 hectares).

A modified acreage grid was also used as a swamplands measurement device for comparison with the other methods (Figure 8). The modified acreage grid consists of 64, one-inch square blocks imprinted on a transparency. These blocks are subdivided into .25 inch (.63 cm) squares with 4 evenly spaced dots in each square (i.e. 64 dots per square inch). To measure the transect wetlands area, the modified acreage grid was dropped over the test site and the number of dots that fell within the swamplands area were counted. This procedure was performed 10 times and the mean of the dot counts was then multiplied by a conversion factor to give an estimate of the wetlands area within the transect site.[26] A total of 876.98 acres (354.91 hectares) were measured from the test area using the modified acreage grid. The area figure represented a difference of -9.48 acres (-3.84 hectares) between the dot planimeter and acreage grid measurements.

Of the three instruments used, the dot planimeter was the most accurate in comparison with the areal dimensions of the wetlands test site obtained from the polar planimeter. The dot planimeter also required less time to measure the test site area than the other methods. The dot planimeter, therefore, was used to measure the wetlands in the remaining transect sites from the medium altitude photo frames. The results of the measurements, based on the mean of ten dot planimeter drop counts per transect, are recorded in Table III.

Landsat Transect Site Scaling and Adjustment Procedure

After all of the wetlands within the 14 transect sites were measured from the medium altitude photography, the next task in the accuracy testing

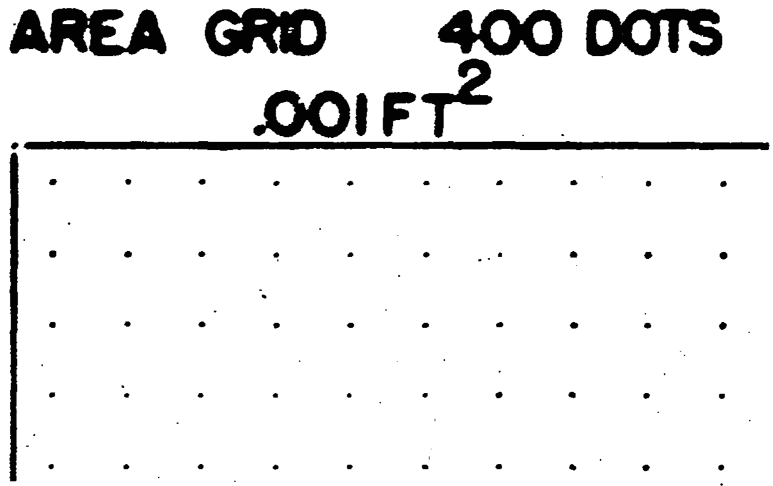


Figure 6. Dot Planimeter

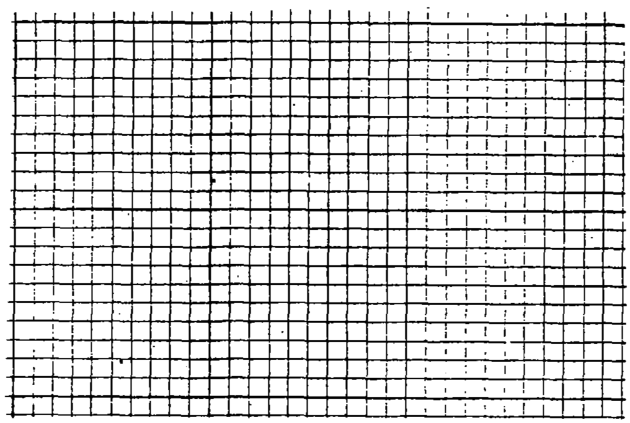


Figure 7. Ten grid cells to the inch

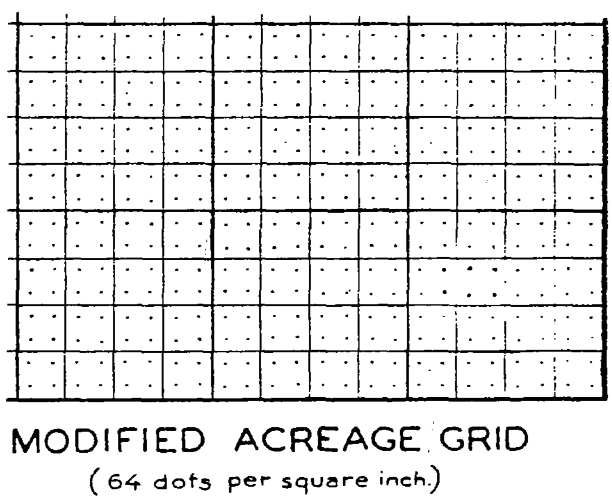


Figure 8. Modified Acreage Grid

procedure was to measure the swamplands from the same transects located on the 1:250,000, 1:500,000, and 1:1,000,000 scale Landsat data used in the study. Before the Landsat wetland measurements could begin, however, it was first necessary to define the exact boundaries of the transects on Landsat which corresponded to the same area covered by the 9 x 9 inch (23 x 23 cm) photo frames from the medium altitude imagery. This operation was performed by constructing 14 transect "blocks" that were proportionally scaled to the Landsat imagery according to the scale of the photo frames used as case study areas. Hence, the transect blocks were smaller scaled replications of the transect sites taken from the medium altitude imagery (Appendix B - 64).

Once the size of the transect blocks had been established for the multiscaled Landsat data used in the study, the blocks were carefully drawn on an overlay sheet for registration with the Landsat imagery. The transect block overlays were then visually registered with the imagery using significant photomorphic features, such as field and forest patterns as guidelines for adjustment.

Although care was taken in adjusting the transect blocks with the Landsat data, the accuracy of the visual registration process was affected by human error. Other factors also created aberrations in the transect scaling and adjustment procedure. First, photogrammetric elements such as photo tilt, lens distortion, or shrinkage and expansion of the film, were not compensated for when determining the scale of the photo frames. The exclusion of these factors influenced the scaling of the transect blocks to the Landsat data, but their effect on the

TABLE III

WETLAND AREA PER TRANSECT AS CALCULATED FROM THE MEDIUM ALTITUDE PHOTOGRAPHY VIA THE DOT PLANIMETER

TRANSECT #	ACRES	HECTARES
1	6,642.19	2,688.06
2	1,564.11	632.99
3	2,448.08	998.72
4	3,812.36	1,542.84
5	3,828.14	1,549.23
6	885.88	358.51
7	2,922.07	1,182.55
8	4,958.16	2,006.54
9	3,467.12	1,403.12
10	3,187.73	1,290.06
11	3,223.33	1,304.46
12	5,556.69	2,248.76
13	5,603.81	2,267.83
14	3,662.77	1,482.26

registration process was mitigated since the average scale was computed for each photo frame. Second, the transect block construction procedure assumed that the scale of the Landsat imagery was 1:1,000,000, 1:500,000, and 1:250,000. In reality, the scale of the data varied slightly because of internal and external geometric errors in the Landsat system. These scale aberrations as the NMAS tests demonstrated, however, had a minimal influence on the scaling of the transect blocks. Third, errors were present in the construction of the transect blocks. Aberrations created by the width of the pencil lead used to draw the blocks, and visual errors in measurement of the blocks from the engineer's scale were an inevitable part of the construction procedure.

Despite the presence of these errors, they had only a minor impact on the transect block construction and registration process. Each transect block had an equal susceptibility to aberrations and these errors, therefore, were relative in their affect on the overall scaling and alignment procedure.

Area Gridding of Multiscaled Landsat Imagery

The next step in the verification procedure dealt with the measurement of wetlands within each transect block on the Landsat 1:1,000,000, 1:500,000, and 1:250,000 scale imagery. The area grid, as opposed to the dot planimeter or modified acreage grid, was used to measure the wetlands from the Landsat transect blocks. In an evaluation of reliability between the three instruments for measuring a test transect block on the 1:250,000 scale imagery (Transect #5 - Confluence of the Middle and South Forks of the Obion River), the area grid provided the most accurate measurements in relation to the wetland area measured from the

medium altitude photo frame. The difference between the amount of area measured via the area grid and the photo frame measurements was +53.45 acres (+21.62 ha), while the dot planimeter and modified acreage grid recorded differences of -72.37 acres (-29.29 ha) and -498.68 acres (-201.81 ha) respectively. Moreover, one goal of the study was to measure the entire West Tennessee wetlands area from the most accurate scale of Landsat data as determined from the reliability testing procedure. The area grid was more efficient for measuring the overall wetlands than either the dot planimeter or the modified acreage grid, since it covered a larger area. Also, the area grid required less movement to determine area, unlike the other instruments which demanded frequent movement to obtain a continuous sample.

To measure the area of wetlands within each transect block from the multiscaled Landsat imagery, the area grid was placed over the transect block and a visual percentage estimate was made of the wetlands in each cell of the area grid that fell within the limits of the transect block. The aggregate percentage estimate of all the cells that covered the wetlands within each transect was then multiplied by a ft^2/ac (m^2/ha) equivalent per cell at the designated Landsat scale. This calculation gave the total area of the wetlands measured within the transect blocks on the mutliscaled Landsat imagery.

A percentage of accuracy expressed in "real" and "absolute" or unrefined proportions was then computed for the total wetland area in each transect block (Appendix B - 67). The real accuracies were computed using 100 percent as the highest attainable accuracy. Absolute accuracies were not based on a 100 percent maximum and were

indicative of over estimations in the measurement of swampland area from the Landsat data.

The percentages were based on the dot planimeter measurements of the medium altitude photo frames, and the Landsat multiscaled imagery grid estimates of the swamplands within the same transect sites (Table IV). These aggregate percentages of accuracy, however, do not account for the size or arrangement of the wetland parcels in relation to the area of the wetlands within the transect (Appendix B - 68). Also, the Landsat accuracy percentages are slightly biased towards the photo frame measurements; non-forested wetlands are extremely difficult to detect on Landsat, whereas they have been enumerated in the dot planimeter measurements of the photo frame transects.

As Table IV indicates, there is not a large deviation in the total percentages of accuracy computer from the three scales of Landsat imagery tested in the study. Nevertheless, the percentages of accuracy presented in Table IV cannot be accepted on face value alone.
Several underlying factors must be considered in an analysis of Table IV. These are: 1) scale; 2) ease of wetland identification and measurement; 3) importance of tonal signature contrast and image clarity; and 4) factors that affect transect block construction and registration.

Scale is the most important element in computing the Landsat percentages of accuracy. The scale of the imagery greatly affects the amount of wetland area that can be estimated from the area grid measurements of the Landsat data. The measurable area within the .10 $inch^2$ (.25 cm^2) cells on the area grid at 1:250,000 scale is proportional to a ratio of 4:1 at 1:500,000 scale and 16:1 at 1:1,000,000 scale.

TABLE IV

LANDSAT AREAL PERCENTAGES OF ACCURACY

Transect#	1:250K	1:500K	1:1000K
1	75.42	77.72	87.89
2	96.98 (103.02)	96.72 (103.29)	98.12
3	96.46	99.80	91.17
4	98.61	91.84	96.79 (103.21)
5	98.92 (101.08)	98.29 (101.71)	99.61
6	94.04 (105.96)	90.16 (109.84)	91.62
7	92.73 (107.28)	97.12 (102.88)	98.21
8	99.74	99.60 (100.40)	94.53
9	98.29 (101.71)	94.01 (105.99)	93.34
10	79.93	72.09	44.23
11	96.70 (103.30)	98.22	94.73
12	96.14	94.67 (105.33)	98.59 (101.41)
13	97.33	96.77	89.41 (110.59)
14	88.22	90.88	85.57
Mean	93.54	92.71	90.27

(Numbers in parenthesis indicate absolute Landsat % of accuracy values).

Thus, the same area contained in four cells at 1:250,000 scale is equivalent to the area in one cell at 1:500,000 scale. At 1:1,000,000 scale the amount of area in one cell is proportional to the area covered by 16 cells at 1:250,000 scale. A larger allowance for visual errors of omission and commission in wetland area estimation per grid cell, therefore, is available at 1:250,000 scale than at 1:500,000 and 1:1,000,000 scale. Conversely, there is also a greater opportunity for precision in visual estimation from the 1:250,000 scale imagery, since the ratio of area to cell size is larger than at 1:500,000 or 1:1,000,000 scale.

Another factor that is associated with scale and cell estimation is the size and configuration of the wetlands that are identifiable on the multiscaled Landsat imagery. At 1:500,000 and 1:1,000,000 scales, small or scattered wetland parcels are more difficult to detect than at 1:250,000 scale. The gridding of these wetland tracts is further complicated by the probability of a greater percentage of wetland cell estimation error at the smaller scales.

Image sharpness is an additional factor which influences the value of the Landsat areal percentages of accuracy. Although the edge sharpness of the 1:1,000,000 scale data is excellent, the improvement in image clarity over the 1:500,000 and 1:250,000 scale data is offset by the relationship of the smaller scale to cell area size, and the effect of errors of omission and commission on the gridding procedure.
For example, a 25 percent grid cell estimation error at 1:250,000 scale created by the indistinct separation of tonal signatures at the wetland fringes is equivalent to 24.91 acres (10 ha). An error of this magnitude, however, would be uncommon at 1:250,000 scale. In contrast, an

estimation aberration of 10 percent at 1:500,000 and 1:1,000,000, which is more the rule than the exception, equals 39.86 acres (16.13 ha) and 159.42 acres (64.52 ha) respectively. Despite the decrease in edge sharpness at 1:250,000 scale, a substantial visual error of commission or omission in gridding wetlands would not significantly affect the percentage of accuracy in comparison to similar aberrations experienced at the 1:500,000 and 1:1,000,000 scales.

Lastly, the factors that affect transect block construction and registration must be considered when assessing the aggregate percentages of accuracy from the multiscaled Landsat imagery. It is easier to measure, construct, and register the transect blocks at 1:250,000 scale than it is at 1:500,000 and 1:1,000,000 scale. Since the transect blocks are constructed using an engineer's scale, there is less chance for human measurement error at 1:250,000 than at the other two image scales. It is also easier to register the transect blocks at 1:250,000 scale since the photomorphic features appear larger. Moreover, any error that is made in the transect block construction and registration procedure is intensified on the smaller scaled Landsat imagery.

Linear Transect Measurements

In addition to the Landsat wetland areal tests, a linear measurement analysis of the wetlands was conducted for comparison with the 10-to-the-inch cell grid measurements of each transect. The linear measurements determined how variances in image clarity and scale affected grid calculations along straight lines that passed through the wetlands in each transect. The linear measurements were also a test of

accuracy for the measurement of cross-sectional phenomena, such as highway construction and channelization.

The linear measurements were initially made along two perpendicular lines which connected the corner fudicial marks on the 9 x 9 inch photo frames used as transect sites. To expedite the procedure, lines were traced on an acetate overlay sheet. The overlay sheet was then fitted to each photo frame, thereby eliminating the need to draw lines for each transect site. Measurements were also made along perpendicular lines which connected the corners of each Landsat transect block for comparison with the medium altitude imagery. A percentage of accuracy was then computed based on how correct the Landsat linear measurements were in comparison with the same measurements on the medium altitude photo frames (Appendix B - 72).

As Table V indicates, the Landsat linear percentages of accuracy generally fall in the 80 to 90 percentile range. Little correlation, however, exists between accuracies for perpendicular measurements within the same transect site on the multiscaled Landsat data. This inconsistency in percentages of accuracy is attributable to several factors: 1) the scale of the imagery and the type of measurement instrument used; 2) image clarity; 3) the size and aggregation of the wetlands or wetland parcels within the transect; and 4) errors in transect block registration.

Scale is the most influential factor in the Landsat linear verification procedure. An engineer's scale was used to measure linear distances on the medium altitude photo frames and the Landsat 1:250,000 scale imagery, while a magnifying hand-held mono-comparator was employed to measure the wetlands from the 1:1,000,000 scale imagery. The compar-

TABLE V

LANDSAT LINEAR PERCENTAGES OF ACCURACY

(Lines 1 & 2)*

Transect#	1:250K	1:500K	1:1000K
1	78.32/93.09	78.94/88.05	83.88/80.05
2	99.10/62.45	98.58/61.61	96.55/58.00
3	99.16/95.48	95.28/93.82	92.84/88.89
4	95.77/92.22	97.73/93.35	91.42/96.04
5	100.00/97.75	98.27/97.81	98.27/97.81
6	90.54/95.93	89.83/98.32	91.26/97.20
7	99.14/69.22	96.04/63.18	99.63/89.66
8	98.91/99.22	82.27/95.25	97.74/95.25
9	93.64/69.59	98.77/82.88	99.50/97.26
10	98.66/97.36	95.81/91.99	87.74/98.13
11	95.44/86.08	95.38/99.78	95.38/81.34
12	96.94/78.23	89.70/98.14	88.71/94.75
13	98.29/94.69	92.88/93.73	88.23/89.47
14	86.58/85.88	89.68/98.57	84.96/97.37
Mean 1 & 2	95.04/86.94	92.80/89.75	92.58/90.09
Total Mean	90.99	91.28	91.34

*Line 1 is the measurement from NW to SE corners; Line 2 is the measurement from SW to NE corners.

ator was equipped with a 15 mm linear scale and measurements were made to the nearest 0.1 mm. There was little problem in obtaining wetland measurements from the 1:250,000 and 1:1,000,000 scale data; both the engineer's scale and the mono-comparator were precise enough at their respective scales to provide reliable visual linear measurements. The quality of image sharpness at 1:250,000 scale and the small scale of the 1:1,000,000 scale data, however, were factors to consider in the linear measurement process.

The mono-comparator was also used for measurement of the linear wetland cross sections on the 1:500,000 scale imagery, although the magnification properties of the instrument caused the swampland tonal signatures to blur. Despite this drawback, the 15 mm scale on the mono-comparator was more precise for measurement at 1:500,000 than was the engineer's scale. Consequently, aberrations produced by the magnification of the mono-comparator were not as serious as those generated by the gross scale of the 1/60th inch measurement on the engineer's scale.

Other factors related to scale which influence the linear measurements are image clarity and the size the aggregation of the wetland parcels within the transects. The edge sharpness and the scale of the imagery determine the amount of wetlands detail that is identifiable on the Landsat data. At 1:250,000 scale the acutance of the imagery is poor in contrast to the 1:500,000 and 1:1,000,000 scale data; details are "fuzzy" and tonal signatures are difficult to separate.
Small, scattered wetlands are detectable on the 1:250,000 scale imagery, but linear measurement of these parcels is difficult because of the reduction in image clarity.

Although the edge sharpness of the imagery is improved at 1:500,000 and 1:1,000,000 scales, the wetlands parcels are smaller in size and, therefore, are more difficult to detect and measure. Also, any error in measurement from the 1:500,000 and 1:1,000,000 scale imagery is accentuated in comparison with the same aberration at 1;250,000 scale because of the small image scale. As Table V illustrates, the improved clarity of the imagery at 1:500,000 and 1:1,000,000 scales over the 1:250,000 scale data increases linear measurement accuracy. These figures result more from error caused by instrument aberrations, however, than by an increase in reliability of the linear measurements at the smaller scales.

Another problem which affects the linear measurements is transect block registration error. Since the linear measurements are made along perpendicular lines within the transect block, any aberration in transect block registration will influence the positioning of the measurement lines in reference to their location on the case study photo frames. An error in registration, therefore, will have significant impact on the reliability of the wetland linear measurements. Although the clarity of the wetlands on the 1:500,000 and 1:1,000,000 scale imagery is sharper than at 1:250,000, it is more difficult to properly register the transect block with the imagery at the smaller scales. The wetland details used for orientation on the imagery are smaller on the 1:500,000 and 1:1,000,000 scale imagery in comparison with the 1:250,000 scale data. Consequently, aberrations in placement of the perpendicular lines for linear wetland measurement are more likely to occur on the smaller scaled data despite the improved edge sharpness over the 1:250,000 scale Landsat imagery.

The factors that affect the linear wetland accuracy procedure, like those that influence the areal percentages of reliability, do not invalidate the results listed in Table V. Since neither the frequency nor the impact of these aberrations can be measured, they must be considered relative overall in an analysis of the Landsat percentages of accuracy. Despite the presence of unavoidable errors, therefore, accurate linear measurements of wetlands or wetland related phenomena can be obtained from Landsat imagery.

Relationship Between Landsat Multiscaled Areal and Linear Percentages of Accuracy

As illustrated by the multiscaled areal and linear percentages of accuracy enumerated in Tables IV and V, Landsat is a reliable medium for measuring wetlands in West Tennessee using visual techniques. A classification accuracy of 85 percent or greater is considered acceptable according to the USGS Land Use and Land Cover System. Based on this reliability figure, the Landsat data tested in the study can be considered accurate for measuring and mapping wetlands in West Tennessee.

Although the mean percentages of accuracy for the Landsat multiscaled areal and linear measurements are greater than 90 percent, there is little correlation between the corresponding transect verification test results in Tables IV and V. A high areal percentage of accuracy consequently, does not assure a correspondingly high linear percentage of precision and vice-versa.

In the linear tests, if a line passes through swamplands that are composed of small, scattered, wetland parcels the area will be difficult

to measure and the linear percentage of accuracy will be poor regardless of the areal percentage. Since the linear percentages of accuracy are the results of two cross-sectional tests of the wetlands in a transect, they may or may not correlate with each other or with their corresponding areal percentages of reliability. The linear percentages of accuracy, therefore, are less significant as a determinant of Landsat wetlands measurement reliability than are the areal accuracy figures. The linear percentages of accuracy are important nonetheless, because they reinforce the results of the NMAS evaluation; the linear figures provide a positive test of the geometric fidelity of the Landsat imagery along a cross-sectional path. Moreover, the linear percentages of accuracy illustrate that point-to-point wetlands data can reliably be measured from Landsat imagery using visual techniques.

Total Area Measurements of the West Tennessee Wetlands from Landsat

Upon completion of the Landsat areal and linear verification procedures, the next research objective was to measure the total wetlands area in West Tennessee via the most accurate scale of Landsat imagery used in the study. The analysis of Tables IV and V illustrated that the problems associated with the 1:250,000 scale imagery were outweighed by the benefits of working at a scale larger than 1:500,000 or 1:1,000,000. Despite the limitations in image clarity at 1:250,000 scale, it was easier to register the transect blocks and measure the wetlands at this scale of imagery in comparison with the smaller scaled data; there was also less chance for error and a greater possibility for precision in the registration and measurement process at 1:250,000 scale

than at 1:500,000 or 1:1,000,000 scale. The 1:250,000 scale imagery also had a higher percentage of overall areal accuracy than the 1:500,000 and 1:1,000,000 scale Landsat data.

The West Tennessee wetlands were visually measured from the 1:250,000 scale imagery using the area grid. The percentage of wetlands in each cell was multiplied by the ft^2/ac (m^2/ha) per cell. At the Landsat scale of 1:250,000, each cell within the 10-to-the-inch grid contained 4,340,277.78 ft^2 (403,221.64 m^2) or 99.64 acres (40.32 ha). The area grid was registered to the Landsat data through the use of an alphanumeric coordinate system that was fitted to the imagery. Measurement data taken from the wetlands within the one inch square blocks on the area grid were referenced with the coordinate system and indexed for use in the calculation of the total West Tennessee wetland area.

At first, the grid measurement procedure was time consuming and difficult. After an initial period of familiarization, however, proficency in the area grid measurement operation substantially increased. The most difficult areas to grid were similar to the problem areas encountered in the Landsat wetland mapping procedure: 1) at the upper reaches and tributaries of the Obion, Forked Deer, and Hatchie Rivers; 2) the measurement of small wetland parcels or areas of broken swamplands; and 3) the identification and measurement of non-forested wetlands from the imagery.

The upper reaches and tributaries of the Obion, Forked Deer, and Hatchie Rivers were the most difficult areas to grid. Wetlands in these areas are narrow and their tonal signatures blend with the surrounding upland forest signatures. The intermixing of evergreen with

deciduous trees on the ridge tops and upland slopes in the eastern portion of the West Tennessee study area, produces a signature similar to that displayed by wetlands. The rolling, dissected topography at the upper reaches compounds the problems caused by the intermixing of evergreen and deciduous vegetation; shadows in the valleys obscure wetlands in many cases and create a signature that mimics that of forested swamplands.

Although the problems encountered in the grid procedure at the upper reaches of the Obion, Forked Deer, and Hatchie Rivers involve visual errors of commission and omission, these aberrations do not radically alter the overall wetland measurements from the 1:250,000 scale Landsat data. It is only at the upper headwaters of the streams, where the wetlands narrow and the tonal signatures become weak, that a definite visual delimitation problem arises. The marginal stretches of wetlands at the upper reaches contain less swampland area in comparison with the downstream wetlands, and the errors associated with these areas are correspondingly reduced.

Broken and small parcels of wetlands also created problems in the wetland area measurement procedure. Agricultural clearing and encroachment have reduced some forested wetland areas to patchwork; gridding these areas was difficult since visual estimation was a piecemeal operation. Parcels of wetlands within the Mississippi River floodplain were difficult to delimit and grid because the wetlands were small and often exhibited weak tonal signatures. Significant visual measurement errors of commission or omission within the Mississippi Alluvial Valley, therefore, were inevitable.

Another source of difficulty in the total wetlands measurement procedure was the identification, delimitation, and gridding of non-forested wetlands from the Landsat 1:250,000 scale imagery. Non-forested wetlands were difficult to detect because their signatures varied in tone and color. Wetlands that recently had been cut-over were detectable because they displayed a light blue-gray signature on the color infrared Landsat imagery. Wetland areas that had once been cleared but were not cultivated at the time the imagery was taken, however, were extremely difficult to identify and measure. The regrowth vegetation of cut-over wetlands exhibited a tonal signature that was almost indistinguishable from the surrounding agricultural lands. Areas with little or no ground cover were extremely difficult to delimit and measure, even when identified on the medium altitude aerial photography, because the tonal signatures intermixed with agricultural or forested areas. Wetlands that had been recently cleared were also difficult to grid at the contact zone with urban areas, such as Jackson, Tennessee, where built-up land encroached into the wetlands and appeared as non-forested swamplands.

The only non-forested wetlands that were positively identified were sandbars and mudflats associated with the Mississippi River. These non-forested wetland areas were included in the West Tennessee measurements if they were connected with the lowlands on the eastern bank of the river. Also, large water bodies associated with significant areas of wetlands, such as Reelfoot Lake, were classified as non-forested wetlands.

Although the problems of delimiting and gridding non-forested wetlands from the imagery result in visual errors of omission and com-

TABLE VI

TOTAL WETLAND AREA (ACREAGES) FROM

LANDSAT 1:250,000 SCALE IMAGERY

Location	Forested	Non-forested	Total
Reelfoot Lake	20,862.43 Ac 8,442.65 Ha	6,285.23 Ac 2,543.60 Ha	27,147.66 Ac 10,986.51 Ha
Obion River North Fork	20,202.82 Ac 8,175.97 Ha		20,202.82 Ac 8,175.97 Ha
Obion River Middle Fork	17,222.61 Ac 6,969.90 Ha		17,222.61 Ac 6,969.90 Ha
Obion River South Fork	15,129.20 Ac 6,122.70 Ha		15,129.20 Ac 6,122.70 Ha
Obion River Rutherford Fk.	697.47 Ac 282.26 Ha		697.47 Ac 282.26 Ha
Obion River Main Channel	35,248.81 Ac 14,265.00 Ha	232.16 Ac 93.95 Ha	35,480.97 Ac 14,358.95 Ha
Obion River Total	88,500.91 Ac 35,815.83 Ha	232.16 Ac 93.95	88,733.07 Ac 35,909.78 Ha
Forked Deer R. North Fork	21,997.32 Ac 8,902.19 Ha		21,997.32 Ac 8,902.19 Ha
Forked Deer R. Middle Fork	25,055.24 Ac 10,139.72 Ha	1,020.30 Ac 412.91 Ha	26,075.54 Ac 10,552.63 Ha
Forked Deer R. South Fork	57,535.57 Ac 23,284.33 Ha	1,715.78 Ac 694.37 Ha	59,251.35 Ac 23,978.69 Ha
Forked Deer R. Total	104,588.13 Ac 42,326.24 Ha	2,736.08 Ac 1,107.28 Ha	107,324.21 Ac 43,433.51 Ha
Hatchie River	104,753.54 Ac 42,393.18 Ha	1,754.64 Ac 710.09 Ha	106,508.18 Ac 43,103.27 Ha
Mississippi River Lowlands	151,041.87 Ac 61,125.81 Ha	4,926.16 Ac 1,993.59 Ha	155,968.03 Ac 63,119.40 Ha
West Tennessee Wetlands Total	469,746.88 Ac 190,103.96 Ha	15,934.27 Ac 6,448.51 Ha	485,681.15 Ac 196,552.47 Ha

Ac = Acres
Ha = Hectares

mission, these aberrations have a minimal affect on the West Tennessee swampland area summary. The majority of the non-forested wetlands within the study area are located at the wetland fringes; they are marginal wetlands, and the errors associated with non-forested wetlands, therefore, do not invalidate the overall measurements from the Landsat 1:250,000 scale imagery.

Results of Wetlands Measurement from Landsat 1:250,000 Scale Imagery and Computation of the Mean Deviation

As Table VI indicates, 485,861.15 acres (196,552.47 ha) of wetlands were measured from the 1:250,000 scale Landsat imagery via the grid cell estimation procedure. Since the mean areal percentage of accuracy for the 1:250,000 scale imagery was 93.54 percent (real) and 96.93 percent (absolute), it was assumed that the total wetland measurements would exhibit the same level of precision. This percentage of accuracy, however, is subject to variation since the individual percentages of accuracy in Table III deviate from their mean at 1:250,000 scale. The dispersion about the mean is caused by the over- and under-estimation of wetlands within the Landsat transect blocks in relation to the swamplands area measured in the 14 photo frames.

The mean deviation was calculated for the forested, non-forested, and overall wetland totals as an index of omission or commission in the areal grid measurement procedure (Table VII) (Appendix B - 82). The mean deviation has been used to measure the dispersion about the mean rather than the standard deviation, because the latter can give unreliable results when the spread about the mean is large; extreme deviations from the mean, therefore, strongly affect the standard devia-

tion from the mean.[27] As the Landsat areal percentages of accuracy indicate, there are only a few extreme deviations from the mean. These deviations would have a pronounced influence on the spread about the mean if the standard deviation had been computed for the areal percentages of accuracy. Also, the calculation of the standard deviation would be statistically tenuous since the wetlands measured from the 14 transect sites are not uniform in size, shape, or composition. Hence, the mean deviation is more useful for presenting a descriptive statistical analysis of the wetland grid estimation variances from the 1:250,000 scale Landsat overall measurements, than is the standard deviation.

Table VII indicates that the total mean deviation wetland residuals equal 26,275.35 acres (10,633.49 ha) and 33,609.14 acres (13,601.43 ha) for the real and absolute deviation percentage values of $\pm$ 5.41 and $\pm$ 6.92 percent, respectively. The aggregate variance in the percentages of accuracy determined from the Landsat 1:250,000 scale wetlands measurements would be a maximum of 98.95 percent (real) and 103.85 percent (absolute), and a mimimum of 88.13 percent (real) and 90.01 percent (absolute). The possibility of over- or under-estimation in the West Tennessee wetland area totals to the maximum or minimum level for the real and absolute mean deviation residuals is remote. Even at the minimum level of real and absolute accuracy, however, the wetlands area aggregate would still be within the 85 percent reliability standards outlined by the USGS Land Use and Land Cover Classification System.

TABLE VII

MEAN DEVIATION EQUIVALENTS AT LANDSAT

1:250,000 SCALE

	Forested	Non-forested	Total
± 5.41% =	25,413.31 Ac	862.04 Ac	26,275.35 Ac
(Real)	10,284.63 Ha	348.86 Ha	10,633.49 Ha
± 6.92% =	32,506.48 Ac	1,102.65 Ac	33,609.14 Ac
(Absolute)	13,155.19 Ha	446.24 Ha	13,601.43 Ha

Comparison of 1:250,000 Scale Measurements to Wetland Measurements from High Altitude Aircraft Imagery

As a test of accuracy, the Landsat 1:250,000 scale overall wetland measurements were compared with a grid cell measurement of the West Tennessee swamplands from 1:130,000 scale, color infrared, U-2 aircraft imagery of the study area (Figure 9). The wetlands were measured independently of the Landsat areal calculations by Dr. Rehder. These grid cell measurements were utilized as an unbiased comparative index for assessing the reliability of the Landsat 1:250,000 scale wetland total area figures. The results of the high altitude measurements along with the corresponding Landsat grid cell computations are listed in Table VIII.

The table illustrates that a close correlation is present between the independently gridded high altitude and Landsat imagery areal measurements for Reelfoot Lake and the Obion, Forked Deer, and Hatchie Rivers. The difference between the two wetland area subtotals is 4,054 acres (1,640 ha); this is equivalent to an agreement of 98.79 percent for the Landsat wetland measurements as compared to the swampland area gridded from the high altitude aircraft imagery.

All of the disparities between the two overall wetland measurements can be explained by the following: 1) The Obion and Hatchie River measurements differ because the wetlands at the upper reaches of the streams are difficult to identify on Landsat, whereas these areas are visible on the aerial photography; 2) The Reelfoot Lake wetland area computed from Landsat is greater than the U-2 measurement because the Landsat measurements extend into Kentucky on the north side of the lake. The wetlands in this area were not mapped from the U-2 imagery

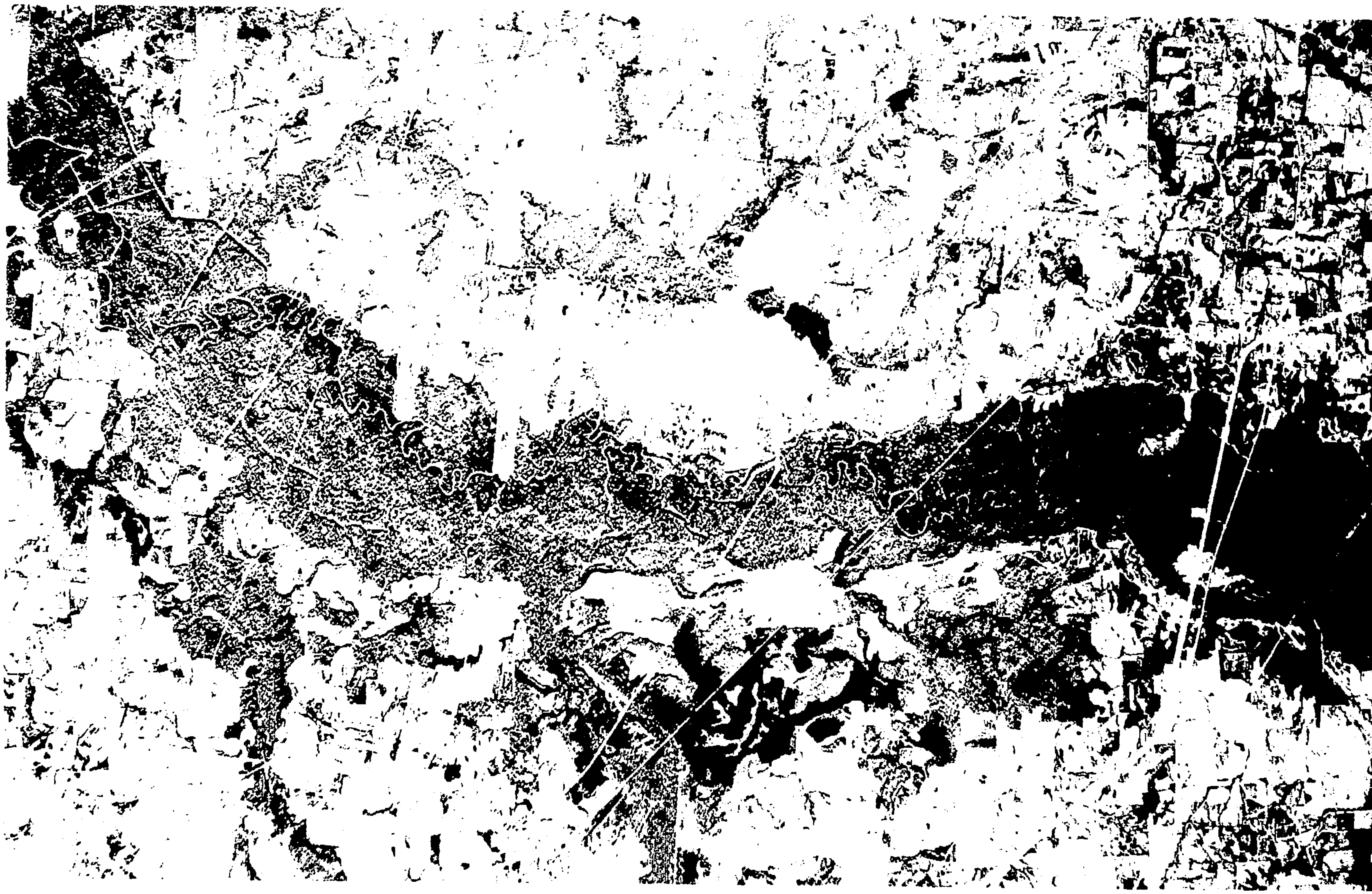


Figure 9. Hatchie River. High Altitude (U-2) Aircraft Imagery. 65,000'. NASA Photo. November 1975

TABLE VIII

COMPARATIVE WETLAND AREAS IN WEST TENNESSEE

	U-2 Aircraft		Landsat	
WETLAND	(Acres)	(Ha)	(Acres)	(Ha)
REELFOOT LAKE	25,641	10,377	27,147	10,986
OBION RIVER	94,492	38,240	88,733	35,909
FORKED DEER R.	99,138	40,121	107,324	43,433
HATCHIE RIVER	114,495	46,335	106,508	43,103
COMPARATIVE SUB TOTALS	333,766	135,073	329,712	133,431

in keeping with the policy of mapping only Tennessee's wetlands; and 3) There is a gap in the high altitude imagery at the confluence of the Middle and South Forks of the Forked Deer River where the wetlands could not be gridded.

A gross discrepancy of 113,566 acres (45,957 ha) was found between the Landsat and high altitude grid measurements of 155,968 acres (63,119 ha) and 42,402 acres (17,160 ha) respectively, for wetlands within the Mississippi Lowlands. This disparity resulted from the different delimitations of the Mississippi Valley as a photomorphic feature, and the misclassification of wetlands within the Lowlands. Since the wetlands were measured independently from the high altitude and Landsat data by different interpreters, their perception of the Lowlands boundaries varied slightly; more wetlands were included in the Landsat data measurements of the Mississippi Lowlands than in the aircraft measurements. Also, tracts of land identified as wetlands within the Lowlands from the Landsat imagery, may not have been classified as swamplands from the high altitude data and vice versus. This misclassification of wetlands may have been exaggerated by temporal differences between the two types of imagery used in the comparative measurement analysis; the Landsat imagery was taken in September, 1972, while the U-2 imagery was flown in November, 1975.

Because of the interpretational problems associated with the measurement of wetlands and the definition of area, the comparative Landsat and high altitude measurements of wetlands within the Mississippi Lowlands were not enumerated in Table VIII. The exclusion of the Mississippi Lowland wetlands from the comparative image measurements, however, does not vitiate the significant correlation in swampland grid

measurements listed in Table VIII. State, local, and federal agencies interested in wetland management within West Tennessee focus their attention primarily on the upland wetlands along the Obion, Forked Deer, and Hatchie Rivers, and the swamplands around Reelfoot Lake. It is in these areas where factors, such as increased erosion from the uplands, sediment pollution, and large scale clearing for agriculture, have adversely affected the wetlands milieu. Hence, the Mississippi Lowland wetlands are considered separately from the upland wetlands because they involve a different set of geomorphological and environmental circumstances.

Despite the large difference between the two Lowland swampland measurements, the comparative percentage of agreement for the Landsat and high altitude measurements along the Obion, Forked Deer, and Hatchie Rivers in the uplands augments the results obtained from the Landsat areal verification procedure. Landsat imagery interpreted through visual techniques, therefore, can be employed by user-oriented agencies as a reliable and economically advantageous alternative to aerial photography for wetlands data collection and management in West Tennessee.

Summary: Landsat Verification Procedure - Part II

In Part II of the verification procedure, the accuracy of Landsat imagery for measuring and mapping wetlands in West Tennessee was tested. The verification procedure was predicated on the wetland areal and linear measurements obtained from 14 photo frame transect sites. These wetland measurements were then compared with areal and linear measurements of the same areas on the Landsat data via 14 transect

blocks that were scaled to the 1:250,000, 1:500,000 and 1:1,000,000 scale imagery used in the study. Areal and linear percentages of accuracy were computed for the Landsat transect blocks relative to swampland measurements derived from case study areas on the aerial photography. An analysis of the verification procedure indicated that three scales of Landsat data used in the study had areal and linear percentages of accuracy greater than 90 percent; the 1:250,000 scale Landsat data, however, was the most reliable scale of imagery for visually measuring and mapping wetlands.

The wetlands of West Tennessee were then measured from 1:250,000 scale Landsat data to obtain an overall swampland area total. This aggregate measurement was compared with an independent wetland measurement taken from high altitude aircraft imagery. The results of these comparative wetland measurement tests illustrated that Landsat imagery is an accurate medium for measuring and mapping wetlands in West Tennessee.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this project has been to verify Landsat imagery as an accurate medium for obtaining near-real time cartographic and geographic information on the wetlands of West Tennessee. Simple, manual techniques have been utilized in the interpretation, mapping, and accuracy testing phases of the study to facilitate the employment of Landsat data for wetlands analysis by a wide range of users. As the results of the study indicate, Landsat imagery is a reliable data source for detecting, identifying, measuring, and mapping wetlands in West Tennessee. The degree of cartographic and measurement accuracy that can be attained from Landsat using visual methods, however, depends upon two interconnected criteria: 1) the interpretative and planimetric qualities of Landsat data, such as the internal geometric distortion, edge sharpness, and scale of the MSS imagery; and 2) the skill of the interpreter.

As the description of the Landsat imagery in the study illustrates, wetland characteristics vary with the spectral band, date, and scale of the data used. Color composite imagery is more useful for wetlands delimitation and mapping in comparison with normal black and white or infrared data because of its false-color properties. The color displayed by wetlands is unique and greatly enhances their detection from the satellite data. Color becomes particularly important when mapping and measuring swamplands at the wetland fringes, at the upper reaches and tributaries of the Obion, Forked Deer, and Hatchie Rivers, within the Mississippi Alluvial Valley, and around urban areas. Associated with the

spectral characteristics of the data for wetlands analysis in West Tennessee are the seasonal aspects of the imagery. Although the signature exhibited by wetlands is the primary key to their delimitation, the color or tone of the swamplands is affected by seasonal dynamics. The ease or difficulty of wetlands detection fluctuates temporally; the amount of water and foliation present are cognitive clues for seasonal swampland mapping from Landsat data.

Paramount in importance as characteristics which affect the visual mapping and measurement of swamplands from Landsat imagery are scale and edge sharpness. The study illustrates that image clarity and measurement error are inversely proportional to scale; i.e., image sharpness decreases at larger scales while the amount of measurement error increases at smaller scales. 1:250,000 scale color composite imagery is the most useful type of imagery for accurately mapping or measuring wetlands from Landsat data. At 1:250,000 scale the clarity of wetlands on the imagery is less sharp than at 1:500,000 and 1:1,000,000 scales, but there is more tolerance for aberration and a greater opportunity for cartographic and measurement precision than at the smaller scales

Although the delimitation of wetlands is directly tied to spectral and seasonal characteristics and the scale of the data, accurate swampland maps and measurements cannot be obtained unless the imagery is planimetrically reliable. The planimetric tests of the study's Landsat imagery data base indicated that the imagery met or approached National Map Accuracy Standards. This test of the imagery substantiated the use of Landsat MSS data as a reliable photomap for the cartographic analysis of wetlands in West Tennessee.

Despite the importance of image quality, scale, or date, one other factor is essential for accurately mapping and measuring wetlands from Landsat data; this is the human element - the perceptive abilities of the interpreter. The Landsat verification and cartographic procedures used in the study were designed for simplicity and reliability for employment by the widest possible number of users. To utilize visual interpretational techniques for wetland delineation in West Tennessee from Landsat imagery, it is not essential that the interpreter have had extensive training in the analysis of remotely sensed data. It is imperative, however, that he be familiar with the study area to achieve accuracy in delineating swamplands.

Field reconnaisance either via ground surveys or from low altitude aerial photography is an integral part of the photo-interpretative process when mapping and measuring wetlands from Landsat imagery. The interpreter must be cognizant of the topographic, vegetational, and geographical parameters that comprise and surround the West Tennessee wetlands to achieve accuracy in the delimitation of wetlands from the imagery. It is also valuable to have first-hand knowledge of how the wetlands change with the seasons; that is, how the wetlands appear at or near ground level at different seasons and how seasonal dynamics are reflected on the imagery. For the development of a wetlands classification scheme or to accurately map and measure wetlands from Landsat data, therefore, the cognizance and perceptive skill of the interpreter are of vital importance.

In conclusion, this study has succeeded in verifying Landsat data as an accurate medium for the geographical analysis of wetlands in West Tennessee. Because manual techniques were employed in this investigation,

the methodology of the study has not been overly rigid in structure; interpretational biases, prejudices, and assumptions are unavoidably a part of the research and its results. These predilections are an integral part of the study, however, since they indicate that the visual classification system utilized in this research can readily be adapted to fit the needs of the user. Wetlands are unique environments and any decision concerning them must take the nuances of the swampland milieu into account. The visual interpretation of wetlands from Landsat data, therefore, offers one significant advantage over machine-processing techniques: each area mapped or measured can be studied to see how it fits into the decision-making framework established by the user.

With care in interpretation of the West Tennessee wetlands from the satellite imagery, the cartographic and measurement accuracies achieved in this work should be attained or exceeded utilizing similar quality Landsat data. The systematic, visual delimitation of wetlands from Landsat imagery, however, must be tested on a regular basis to provide further confirmation of the results of this research. It is hoped that this study will be a progenitor for other more in-depth analyses concerning the utilization of Landsat data for the examination of wetlands. The preliminary investigative stage of research is over and the applications-oriented phase is now ready to commence; in essence, the experimental "ball" is now in the "court" of the users. Only through application by interested individuals and agencies will the utilization of Landsat imagery as an accurate and economically attractive data collection medium become a reality.

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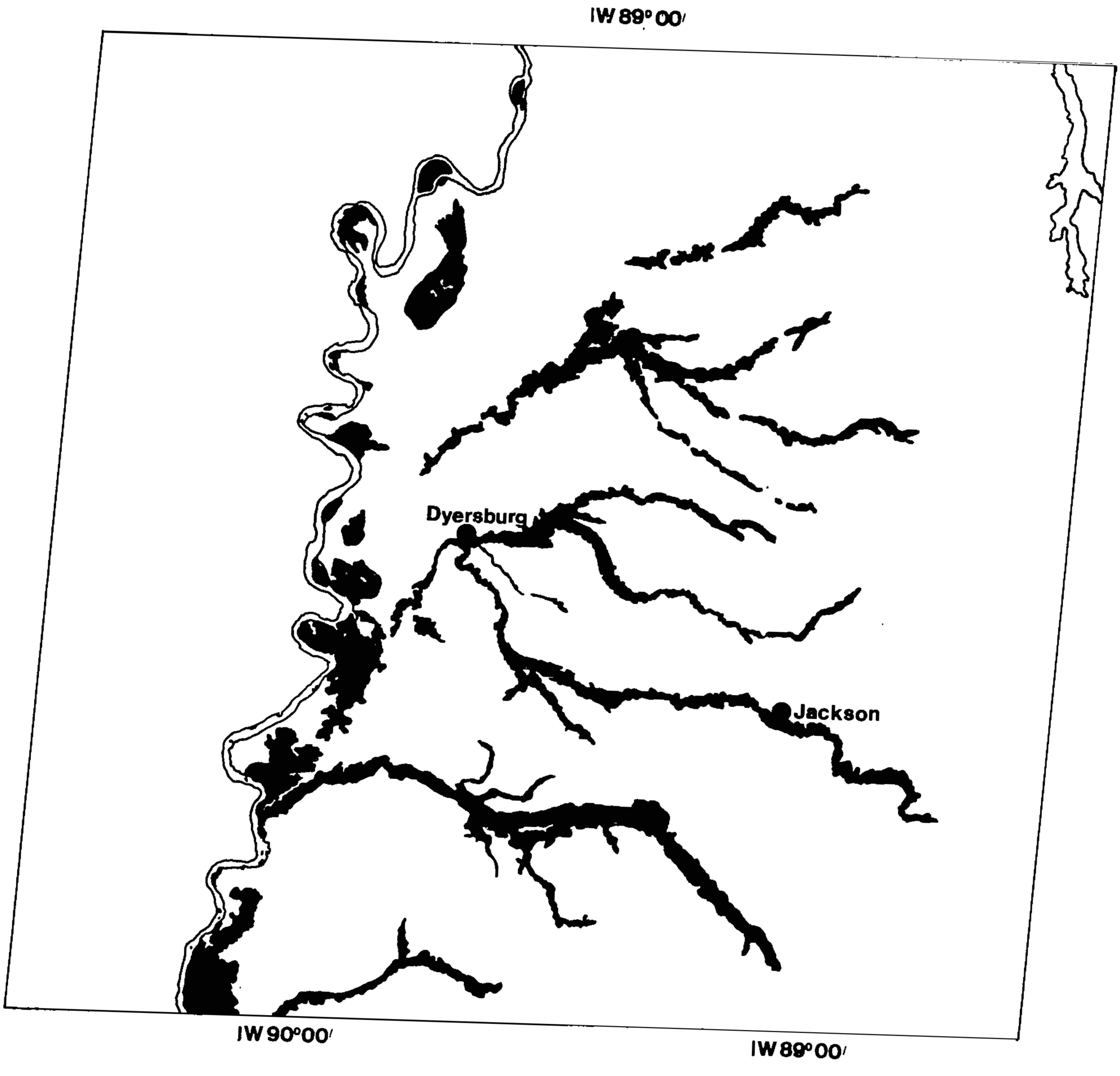
APPENDIX A

LEGEND FOR MAPS 3 - 17

Wetland

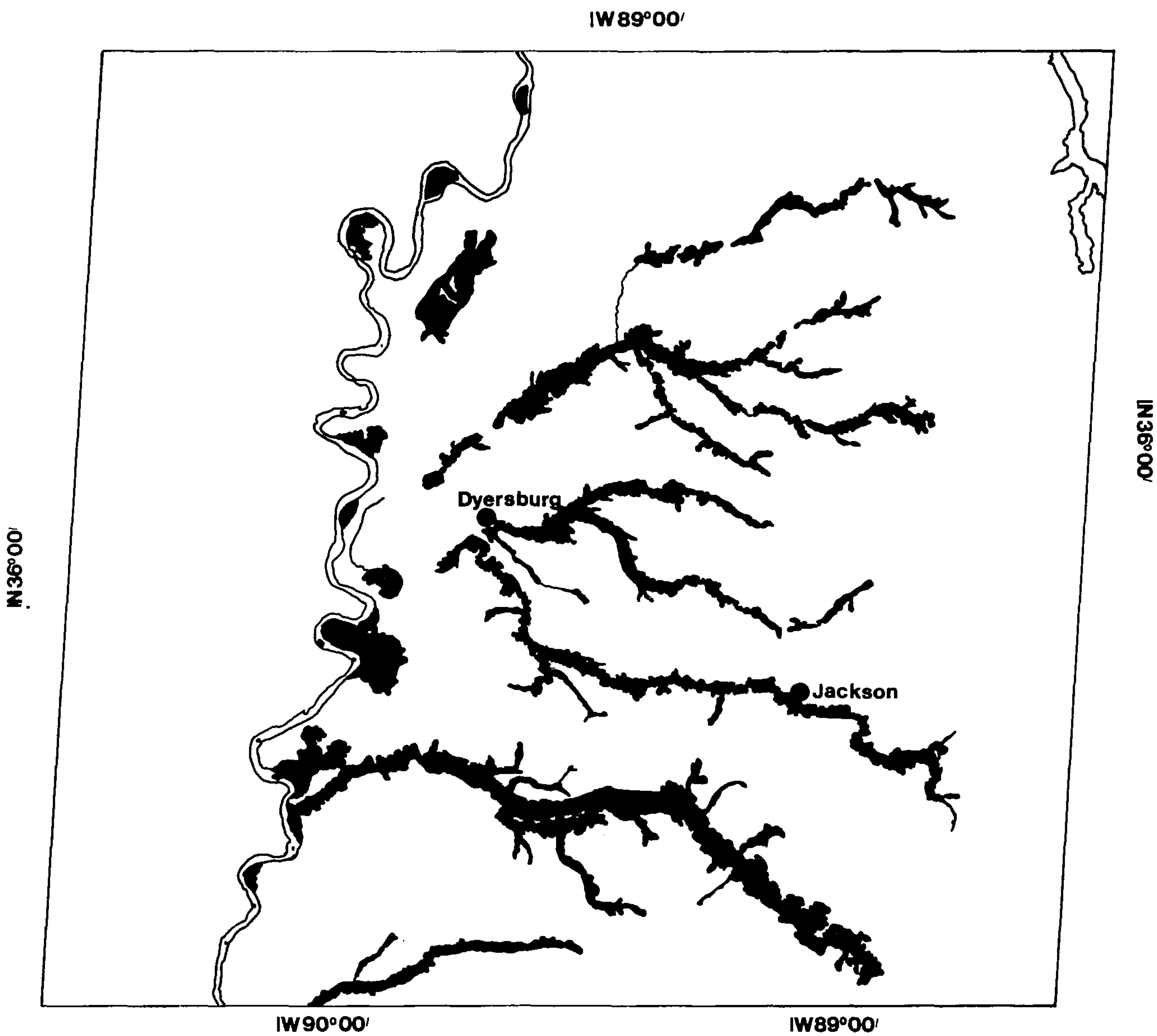
Water (Flooded Land/Lakes)

Urban Areas



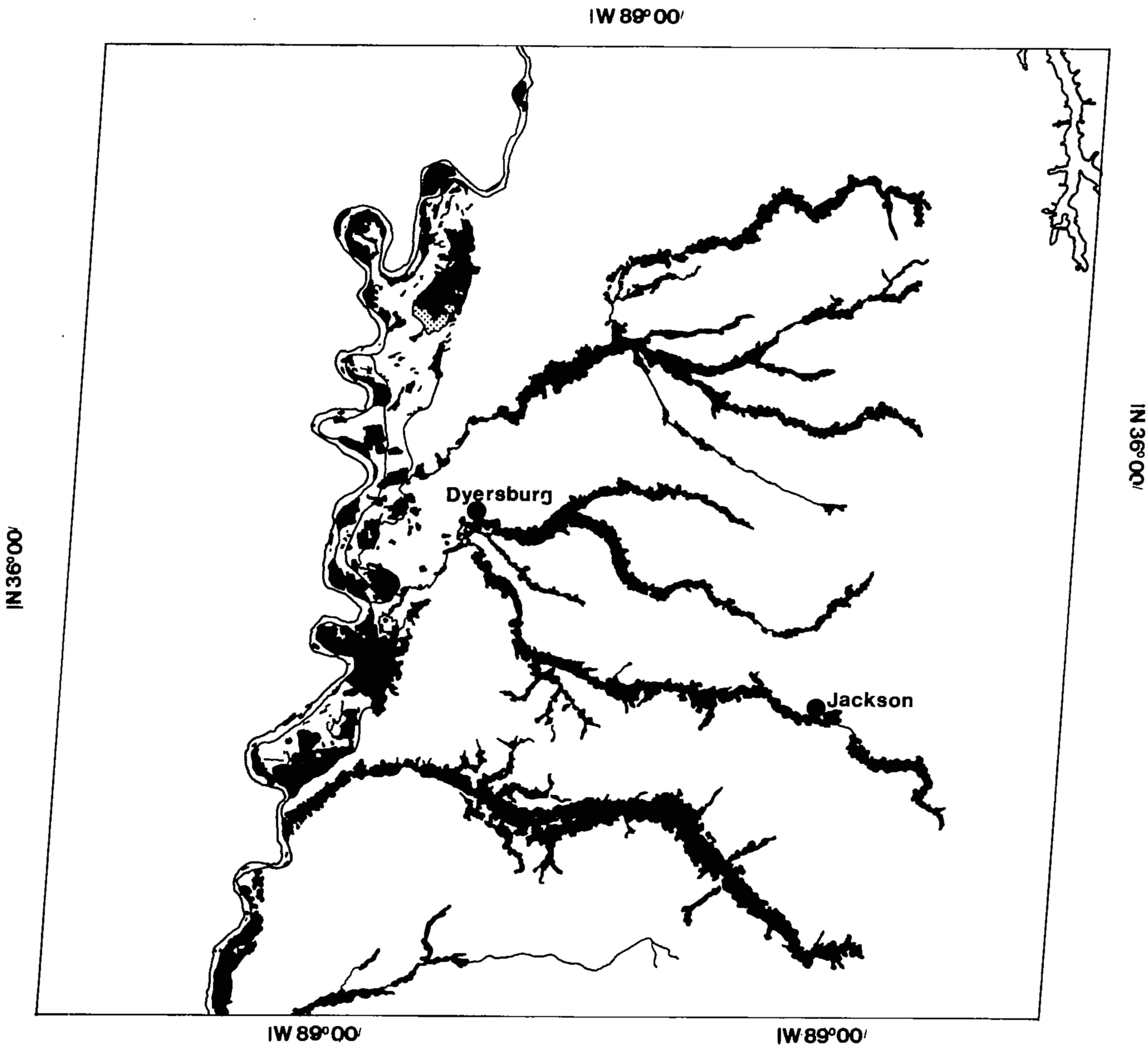
MAP 3

SEPTEMBER 13, 1972 - BAND 4

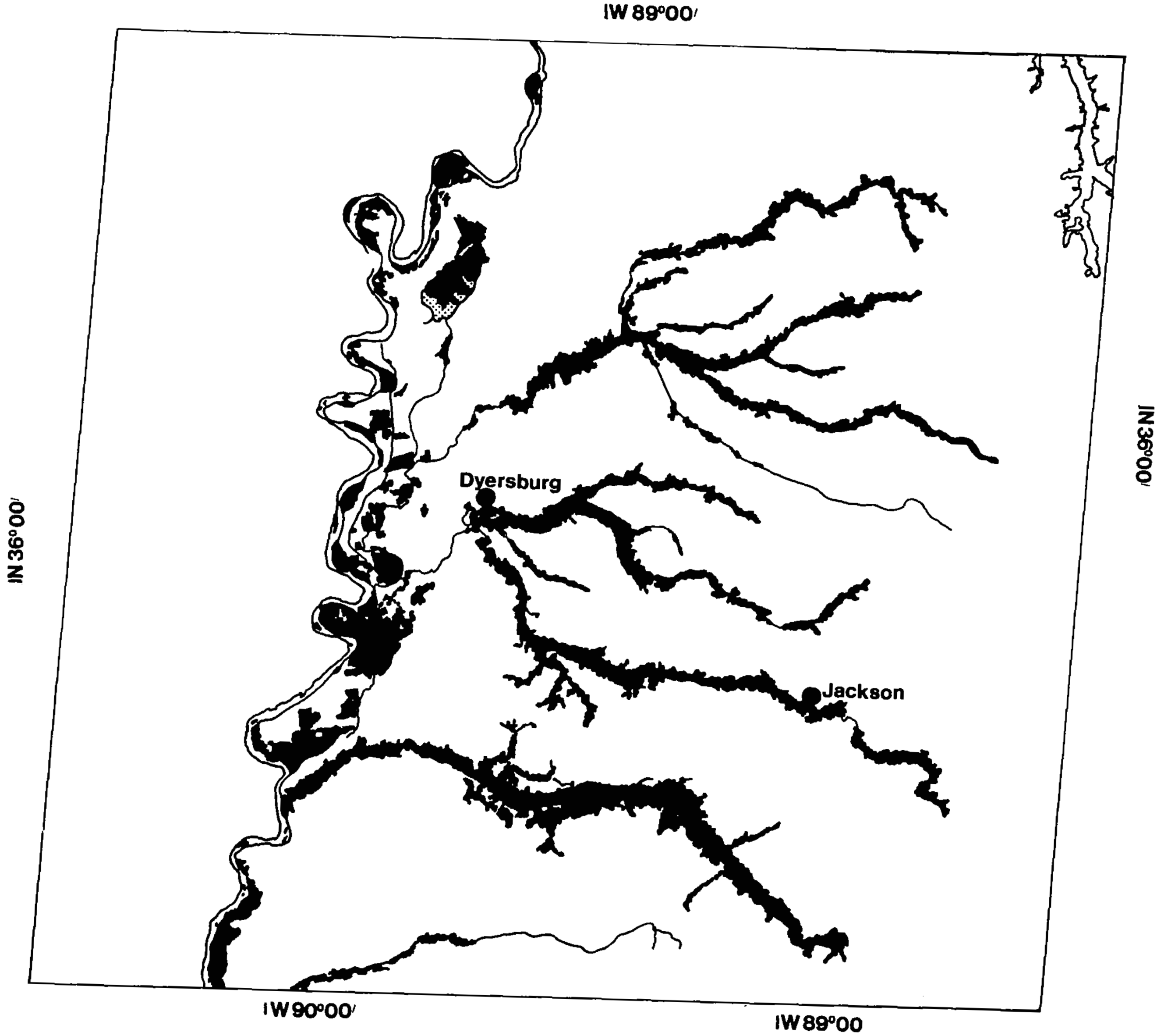


MAP 4

SEPTEMBER 13, 1972 - BAND 5

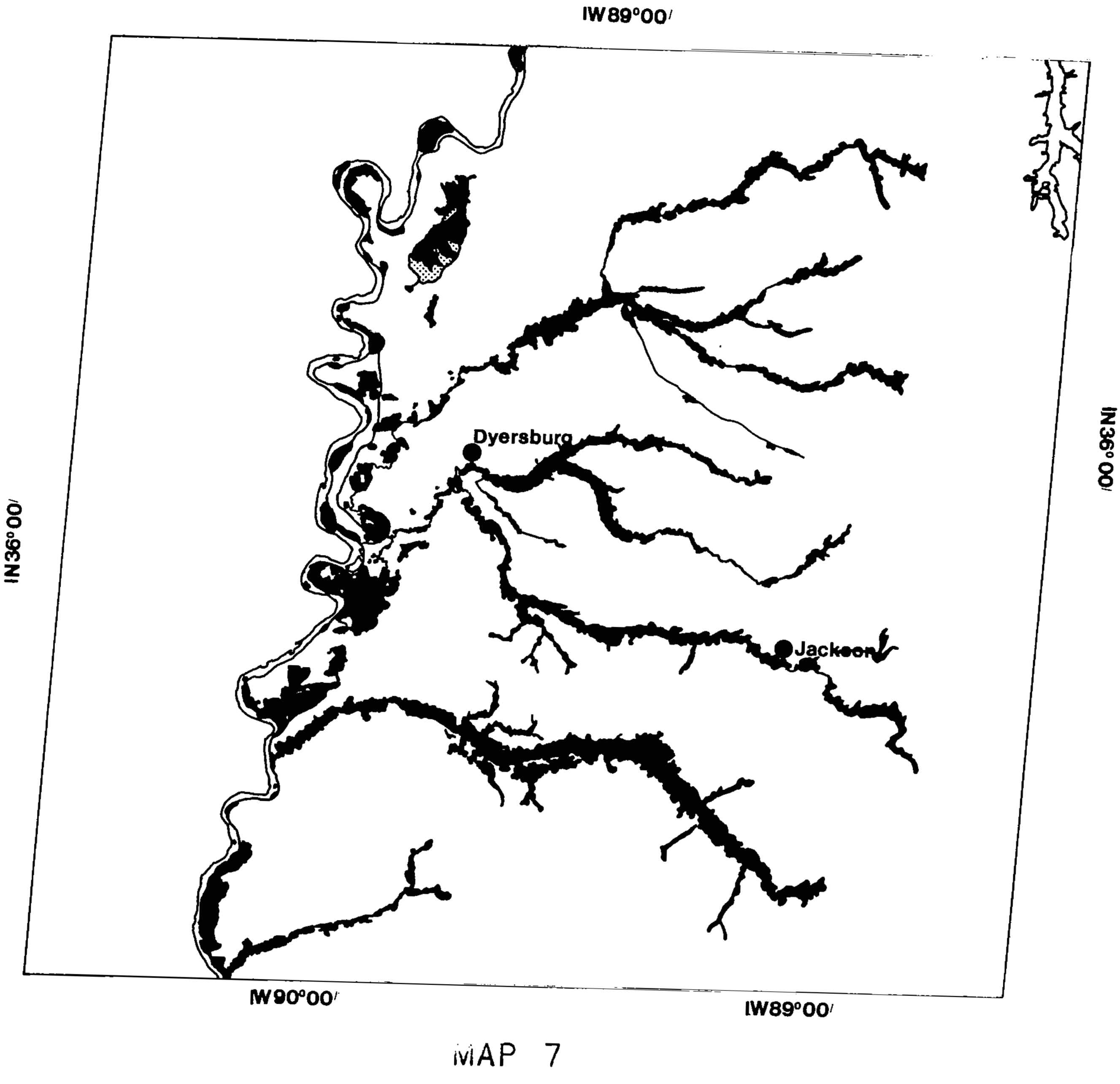


MAP 5
SEPTEMBER 13, 1972 - BAND 6



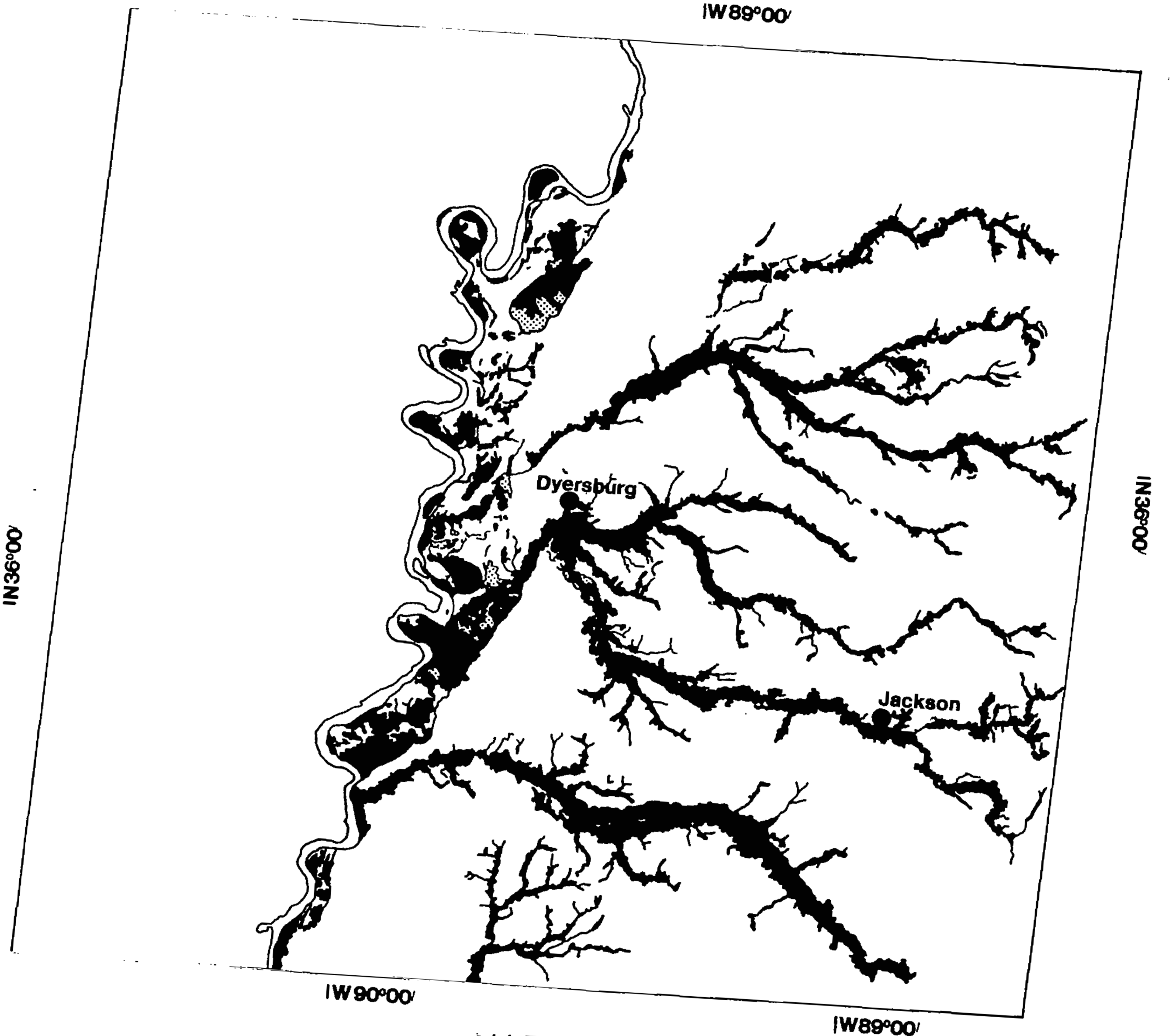
MAP 6

SEPTEMBER 13, 1972 - BAND 7



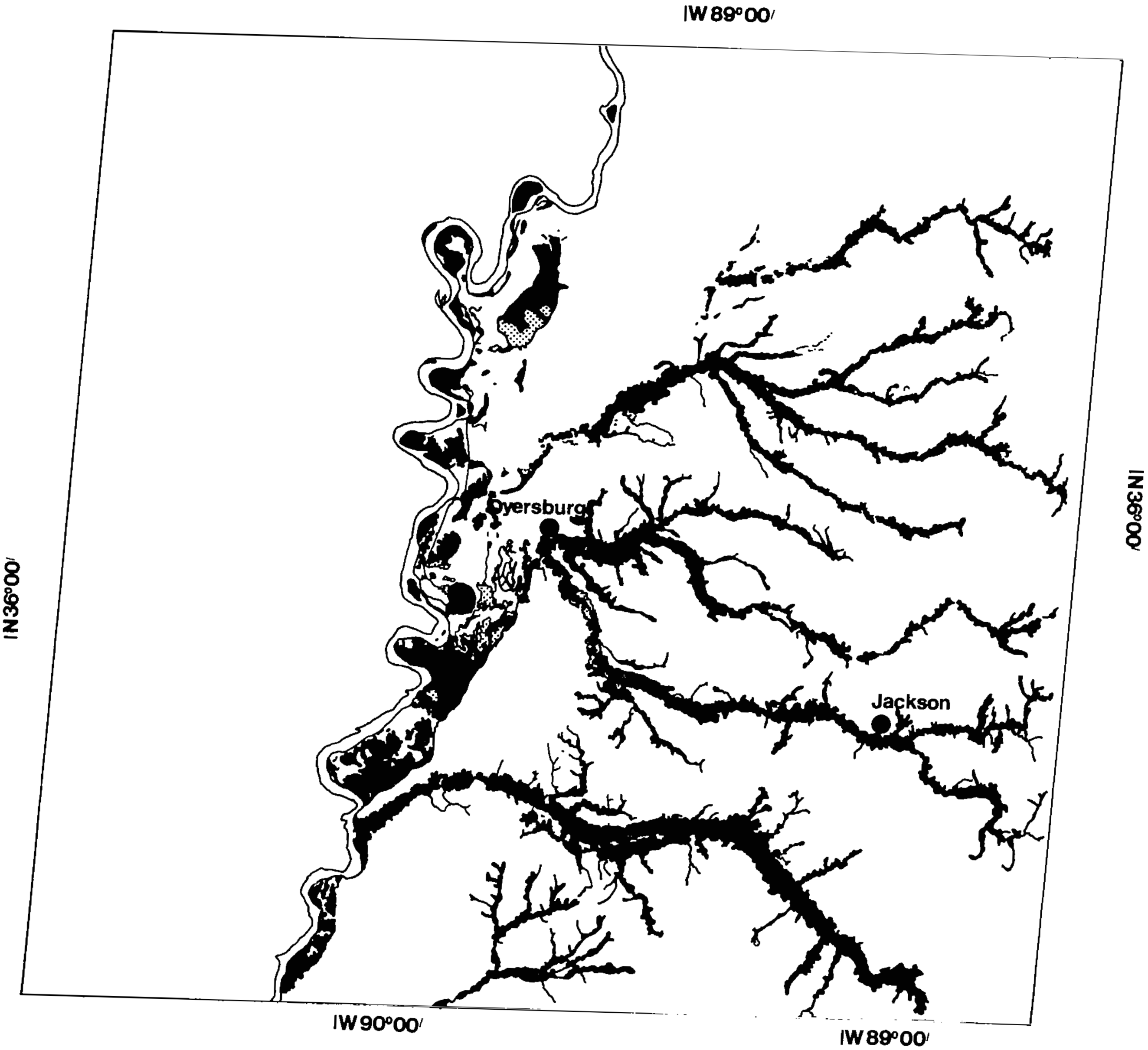
MAP 7

SEPTEMBER 13, 1972 - COLOR COMPOSITE



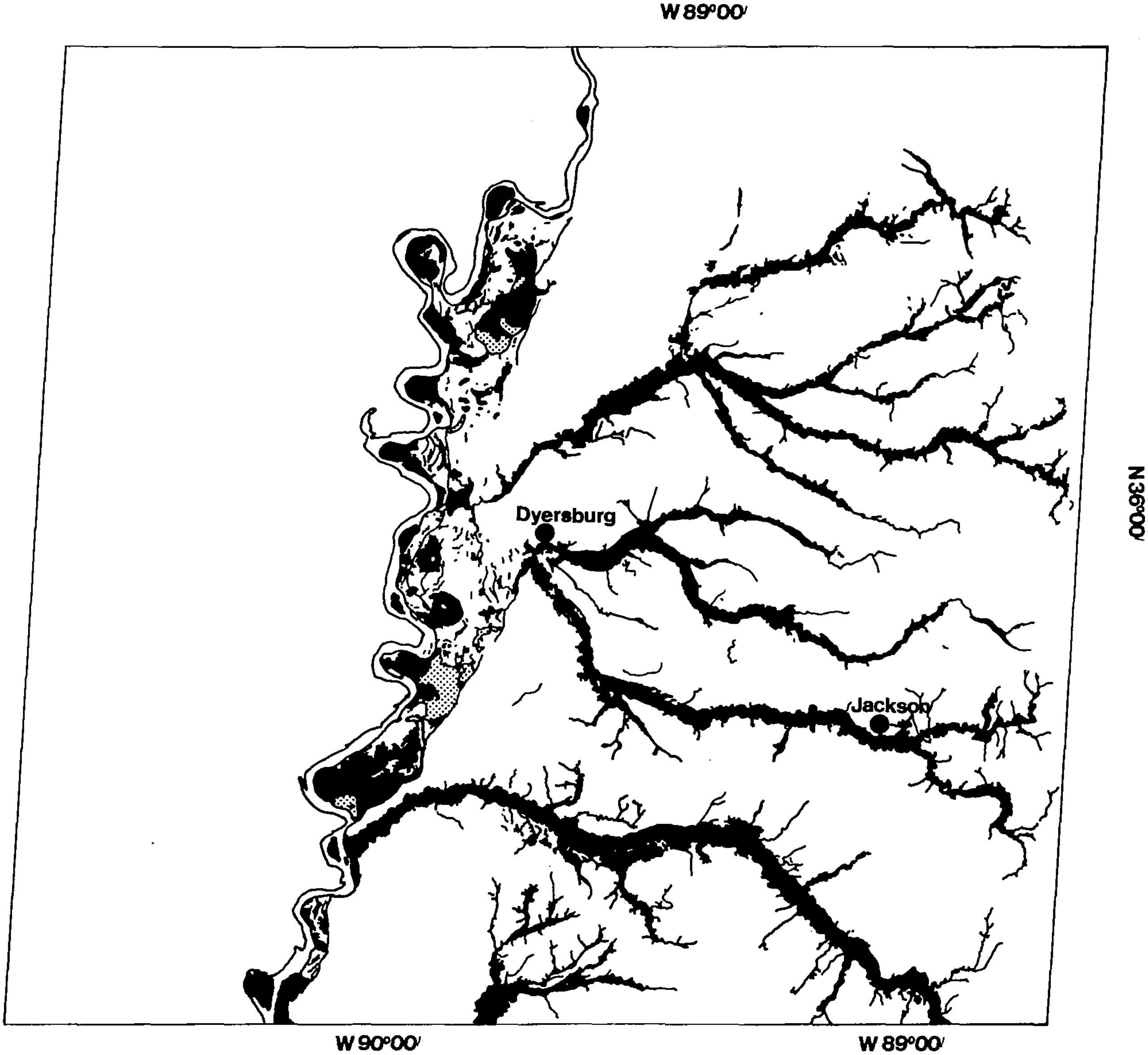
MAP 8

FEBRUARY 22, 1973 - BAND 4



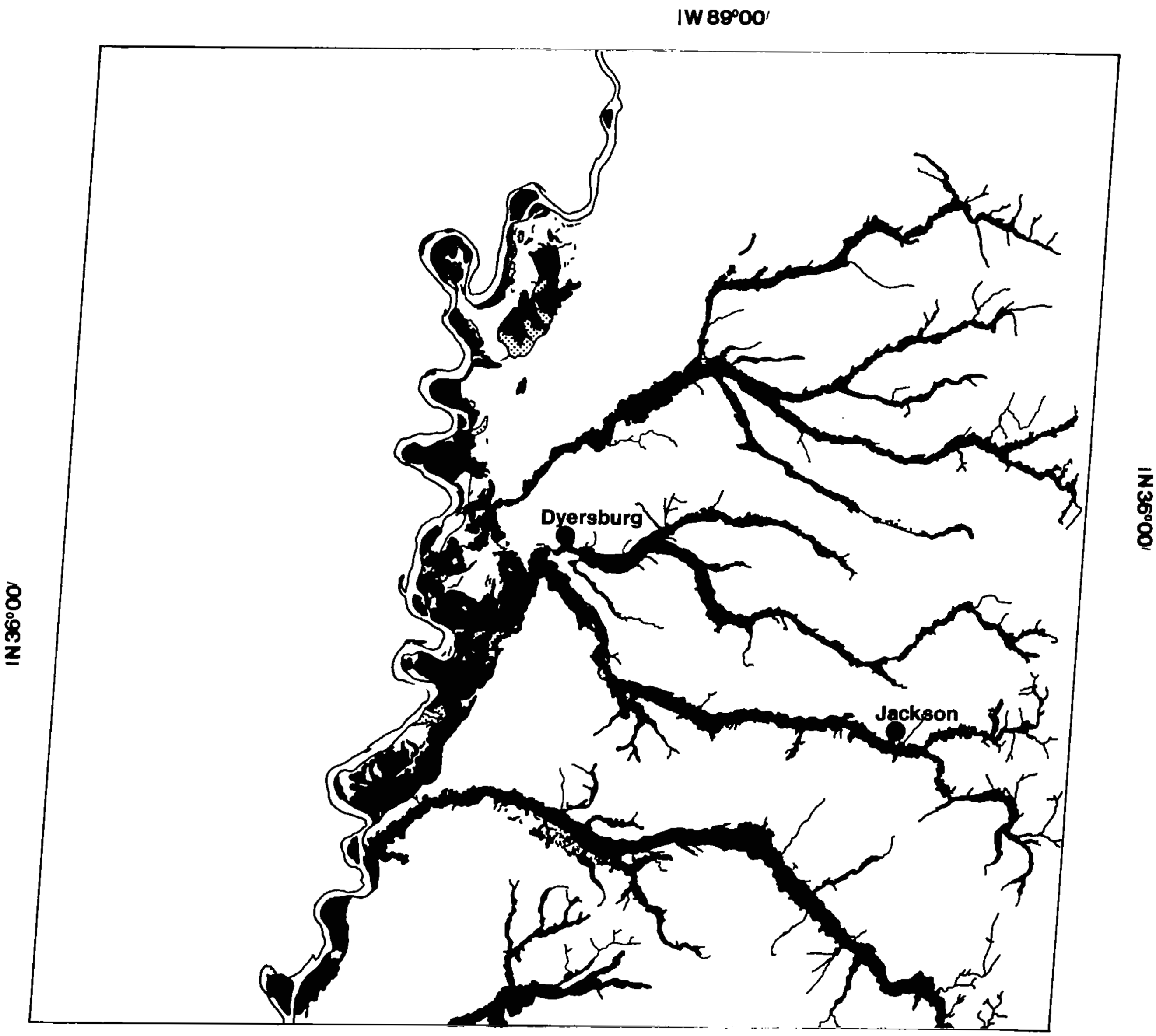
MAP 9

FEBRUARY 22, 1973 - BAND 5



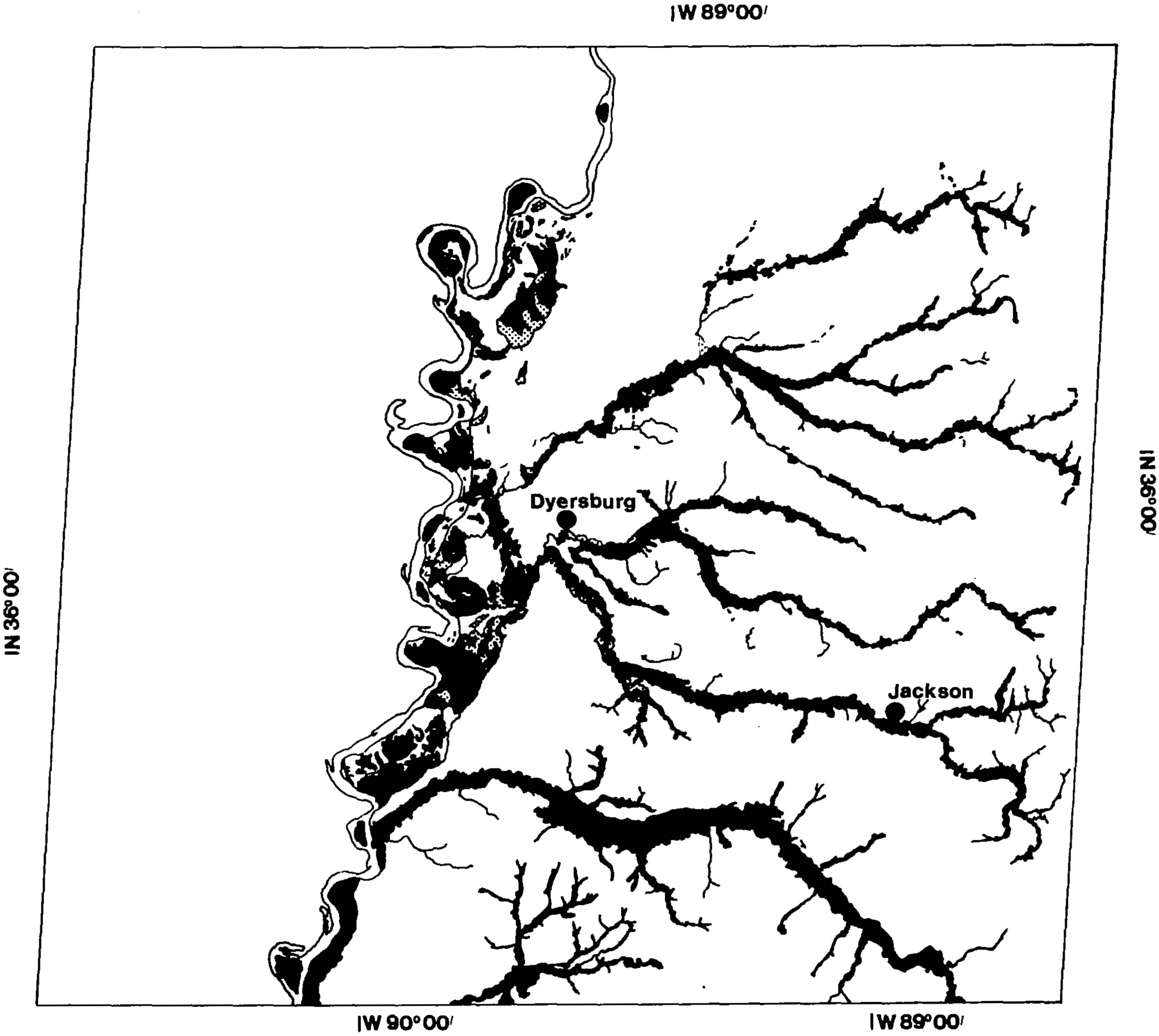
MAP 10

FEBRUARY 22, 1973 - BAND 6



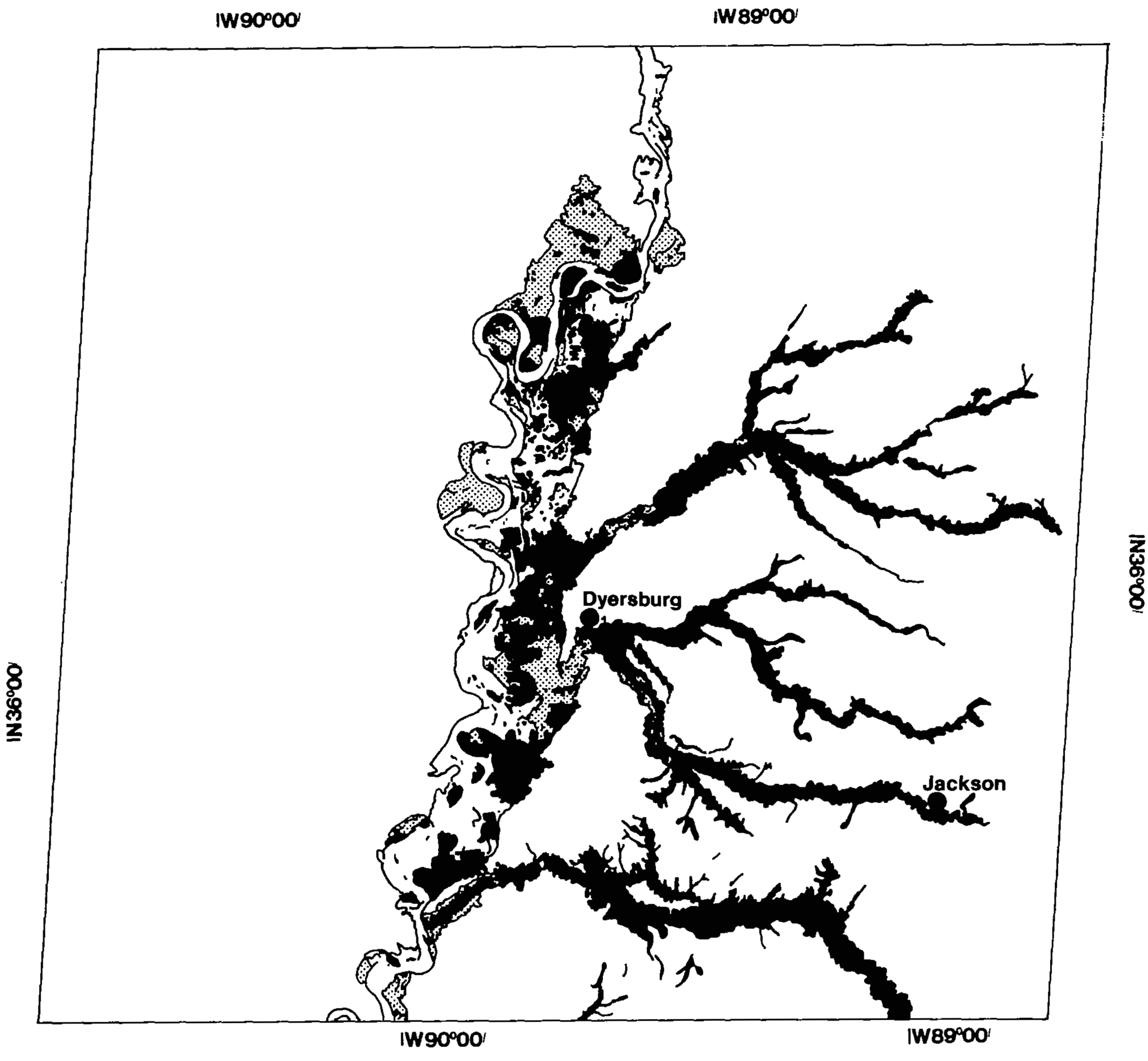
MAP 11

FEBRUARY 22, 1973 - BAND 7



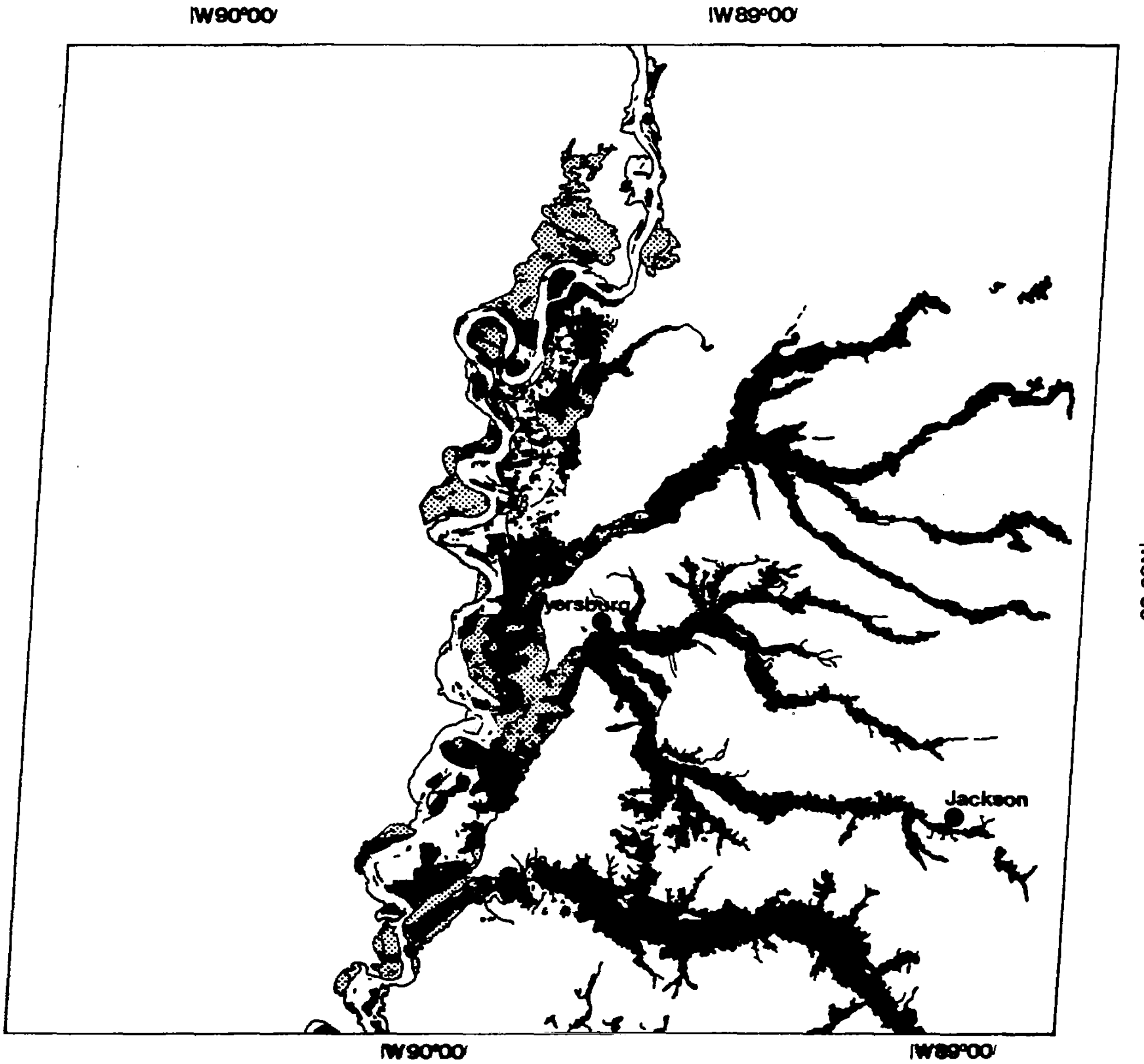
MAP 12

FEBRUARY 22, 1973 - COLOR COMPOSITE



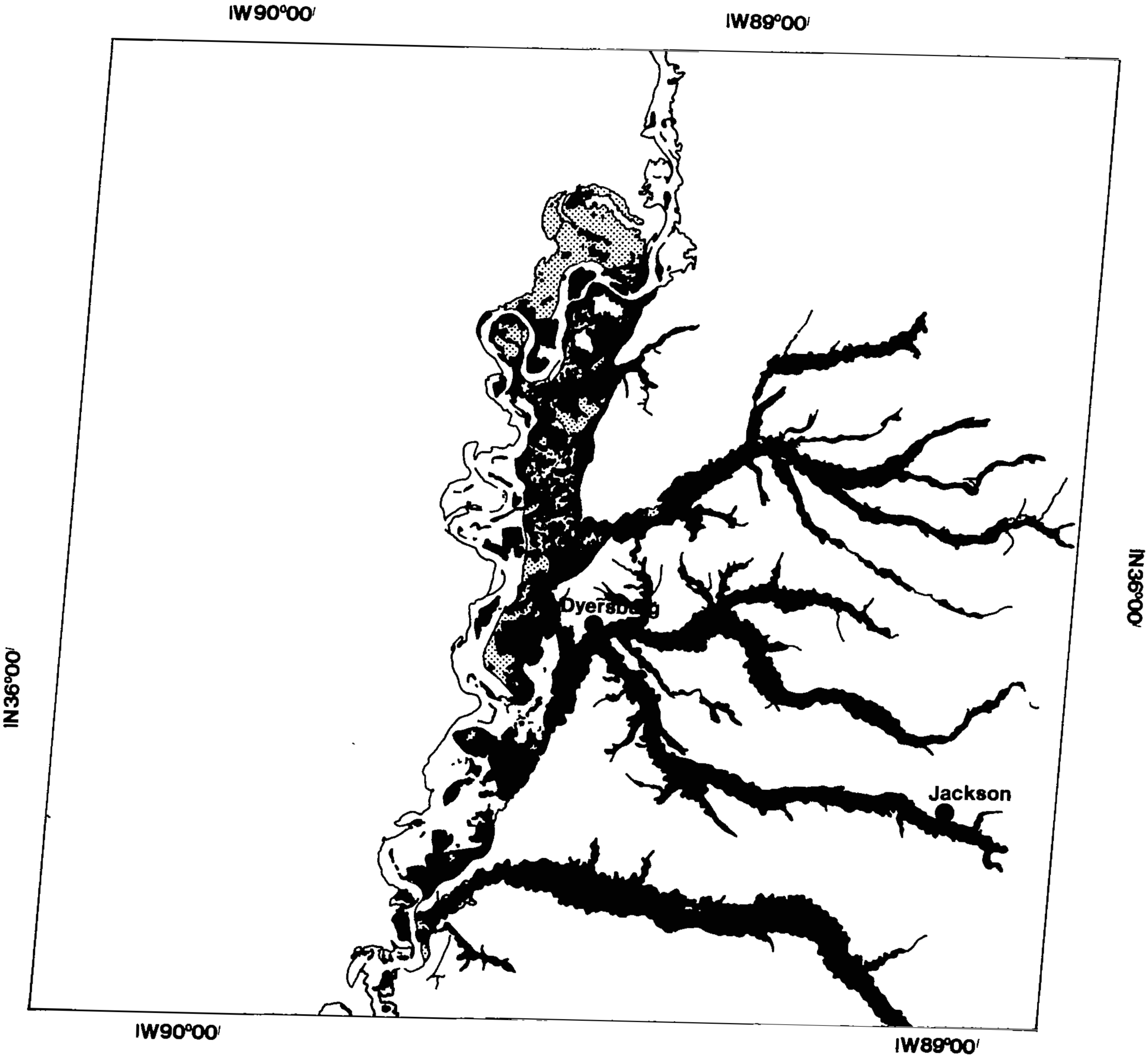
MAP 13

MAY 5, 1973 - BAND 4



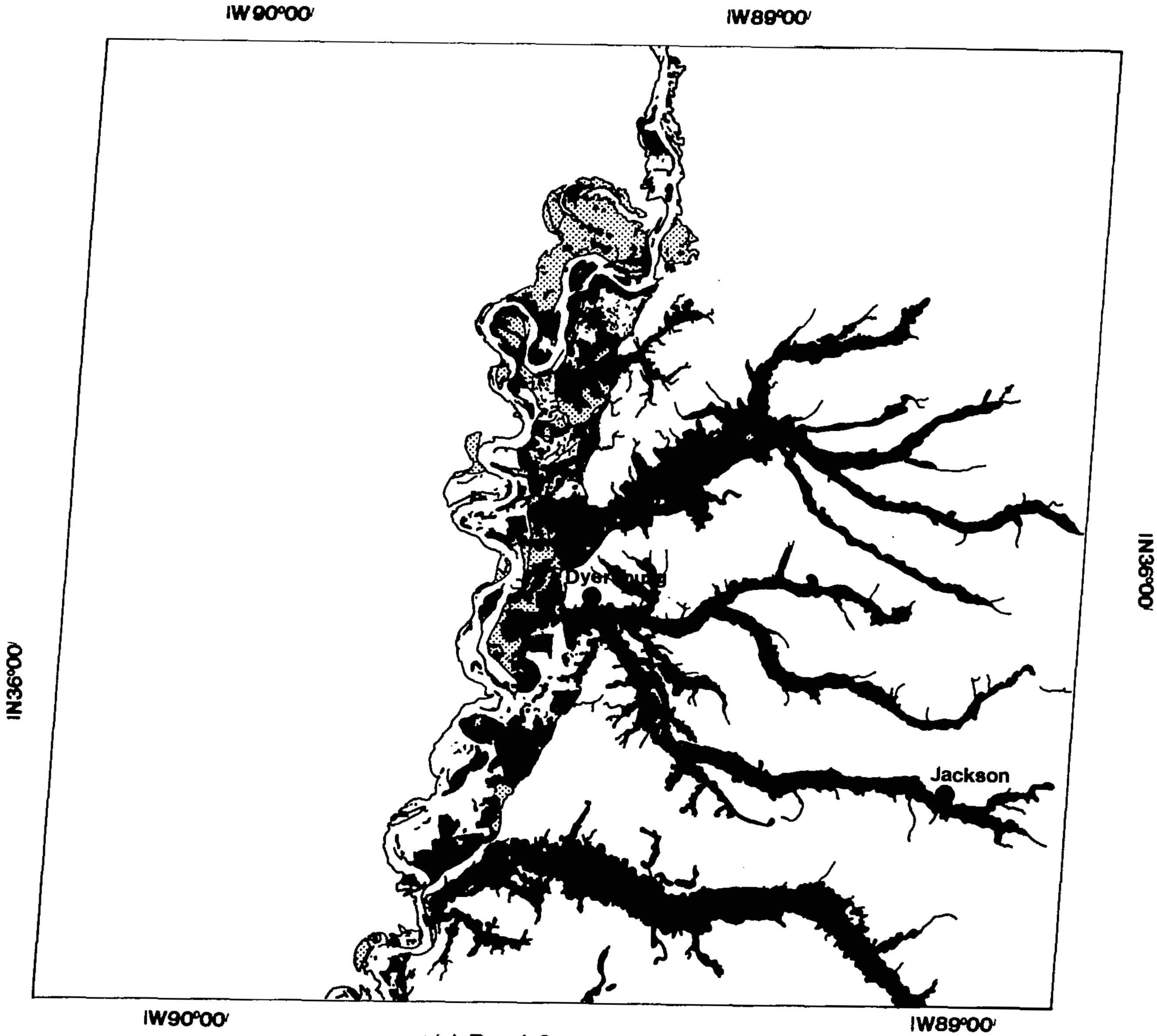
MAP 14

MAY 5, 1973 - BAND 5



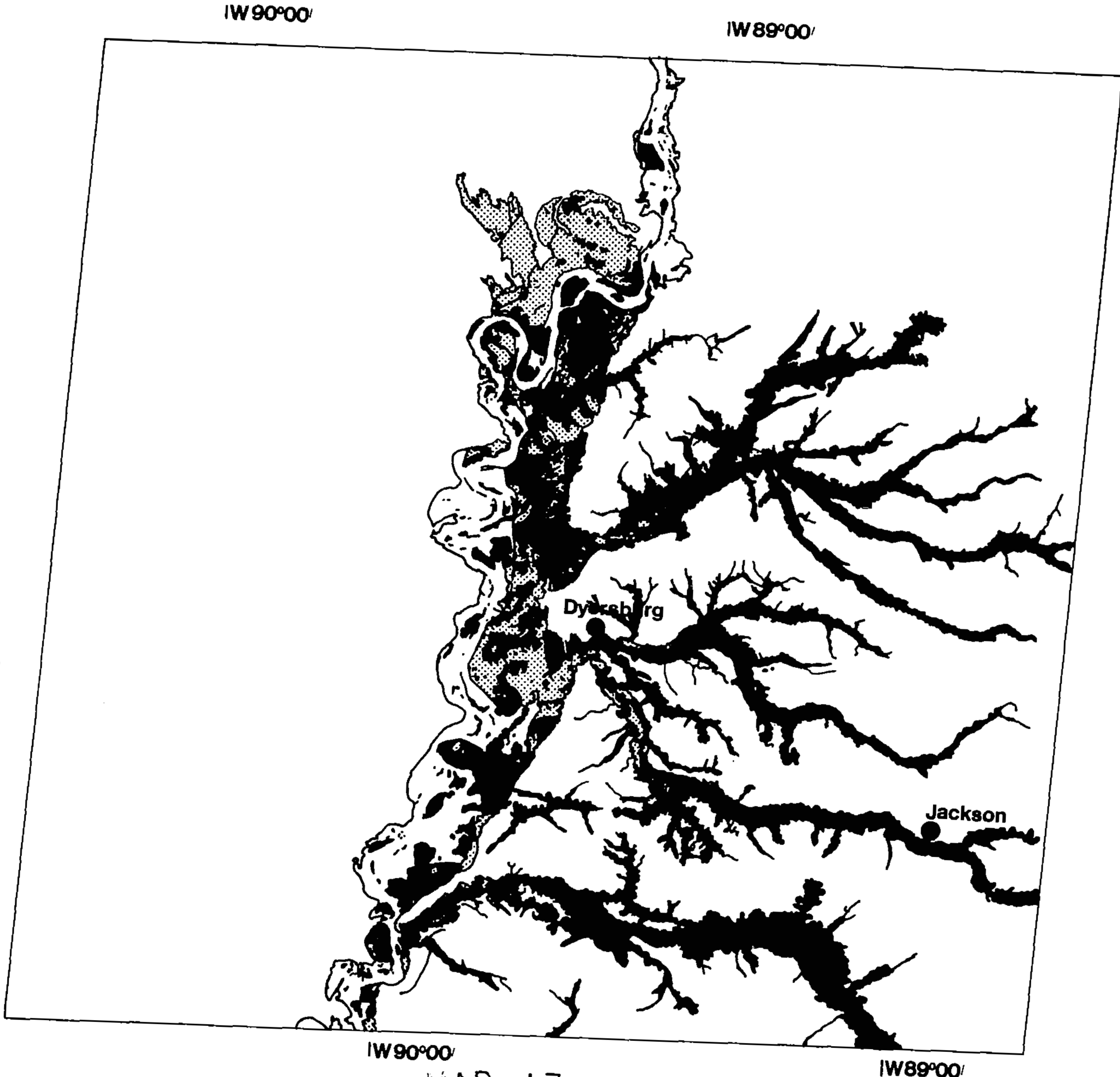
MAP 15

MAY 5, 1973 - BAND 6



MAP 16

MAY 5, 1973 - BAND 7



MAP 17

MAY 5, 1973 - COLOR COMPOSITE

APPENDIX B

Chapter III

(48) The root-mean-square (rms) of a set of N values is defined to be the square root of the mean of their squares;[23] that is

$$\text{rms} = \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}}$$

e.g. Given values of 2,5, and 10:

$$\text{rms} = \sqrt{\frac{2^2 + 5^2 + 10^2}{3}} = \sqrt{\frac{129}{3}} = \sqrt{43} = 6.557$$

(56) Average photo scale is the scale at the mean elevation of the terrain covered by a particular photograph.[25] The average photo scale is expressed as:

$$S_{avg} = \frac{f}{H - h_{avg}}$$

Where f = camera focal length, H = airplane altitude, and h_{avg} = average terrain elevation.

Chapter IV

(64) Each transect block was constructed using the following procedure: 1) The total ft^2/ac (m^2/ha) per inch of the entire transect, not just the amount of wetlands present, was computed according to the scale of the photo frame used as a transect site (e.g. scale of the photo = 1:25,465; 1 inch = 2,122.08 ft [647.23 m]; 1 square inch = 4,503,237.67 ft^2 [418,360.93 m^2] or 103.38 ac [41.84 ha]; therefore, this particular 9 x 9 inch [23 x 23 cm] photo frame = 81 square inches [529 cm^2] or 364,762,251.4 ft^2

[33,886,310.93 m^2] or 8,373.79 ac [3,338.72 ha]; 2) The square root of the total ft^2/ac (m^2/ha) of each 9 x 9 inch (23 x 23 cm) photo frame was then computed to find the length of one side of the transect block in feet (m) at the photo scale (e.g. $\sqrt{364,762,251.4}$ = 19,090.75 ft) 5,818.86 m]). The result of this calculation was then divided by the feet per inch at the Landsat scale (e.g. 2,083.33 ft [635.16 m] per inch at the Landsat scale of 1:250,000) to give the length of one side of the transect block (e.g. $\frac{19,098.75 \text{ ft}}{20,833.33 \text{ ft}}$ = .91674 inch at 1:250,000); 3) This figure was then multiplied by 60 so that the transect block could be constructed at the three scales of Landsat using an engineer's scale (e.g. .91674 inch x 60 = 55.00 1/60ths for one side of the transect block at the Landsat scale of 1:250,000).

(67) The areal percentage of accuracy was computed using the formula:

$$100 - \left| \frac{\text{\% Wetlands are of Total Area of Photo Frame - (minus) \% Wetlands are of Total Area of Landsat Transect Block}}{\text{\% Wetlands are of Total Area of Photo Frame}} \right|$$

(68) The smaller the size of the individual wetland parcel, the higher the percentage of error, not because there was less detectable aggregate area in relation to the medium altitude photo frame, but because small wetland parcels were not image-identifiable on the Landsat imagery. The minimum wetland area that could reliably be estimated from Landsat was .10 of a cell. This was equivalent to 9.96 acres (4.03 hectares) at 1:250,000 scale; 39.80 acres (16.13 hectares) at 1:500,000 scale; and 15,942.25 acres (645.15 hectares) at 1:1,000,000 scale. The scale of the imagery, therefore, had as much influence on parcel size measure-

ment as did the recognizability of the smallest wetland tracts on the multiscaled Landsat imagery.

(72) The linear percentage of accuracy was computed using the formula:

$$100 - \left| \frac{\text{\% Wetlands are of Total Photo Frame Linear Distance (minus) \% Wetlands are of Total Area of Landsat Transect Block Linear Distance}}{\text{\% Wetlands are of Total Photo Frame Linear Distance}} \right|$$

(82) Mean deviation = $\dfrac{\sum_{i=1}^{N} |X - \bar{X}|}{N}$

The mean deviation represents the arithmetic mean of the absolute difference of each score from the mean.[27]

e.g. $\dfrac{\sum_{i=1}^{N} |X - \bar{X}|}{N} = \dfrac{1 + 8 + 13 + 4 + 16}{5} = \dfrac{42}{5} = 8.4$

APPENDIX C

LEGEND FOR MAPS 18 - 31

Forested Wetland

Non-Forested Wetland

Marsh

Dead Timber

Flooded Land

Saturated Agricultural Land

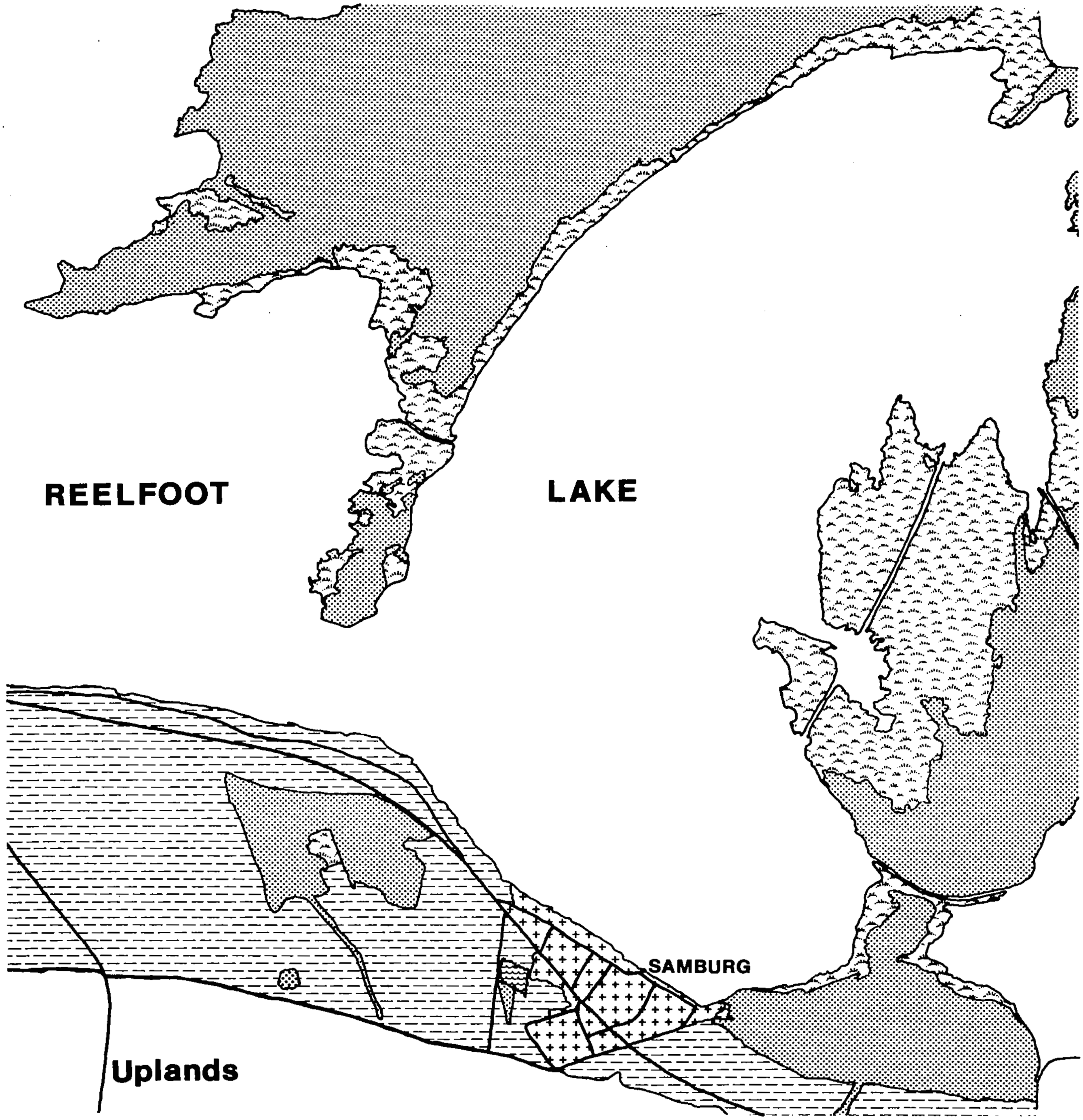
Urban or Built-up Land

Lakes

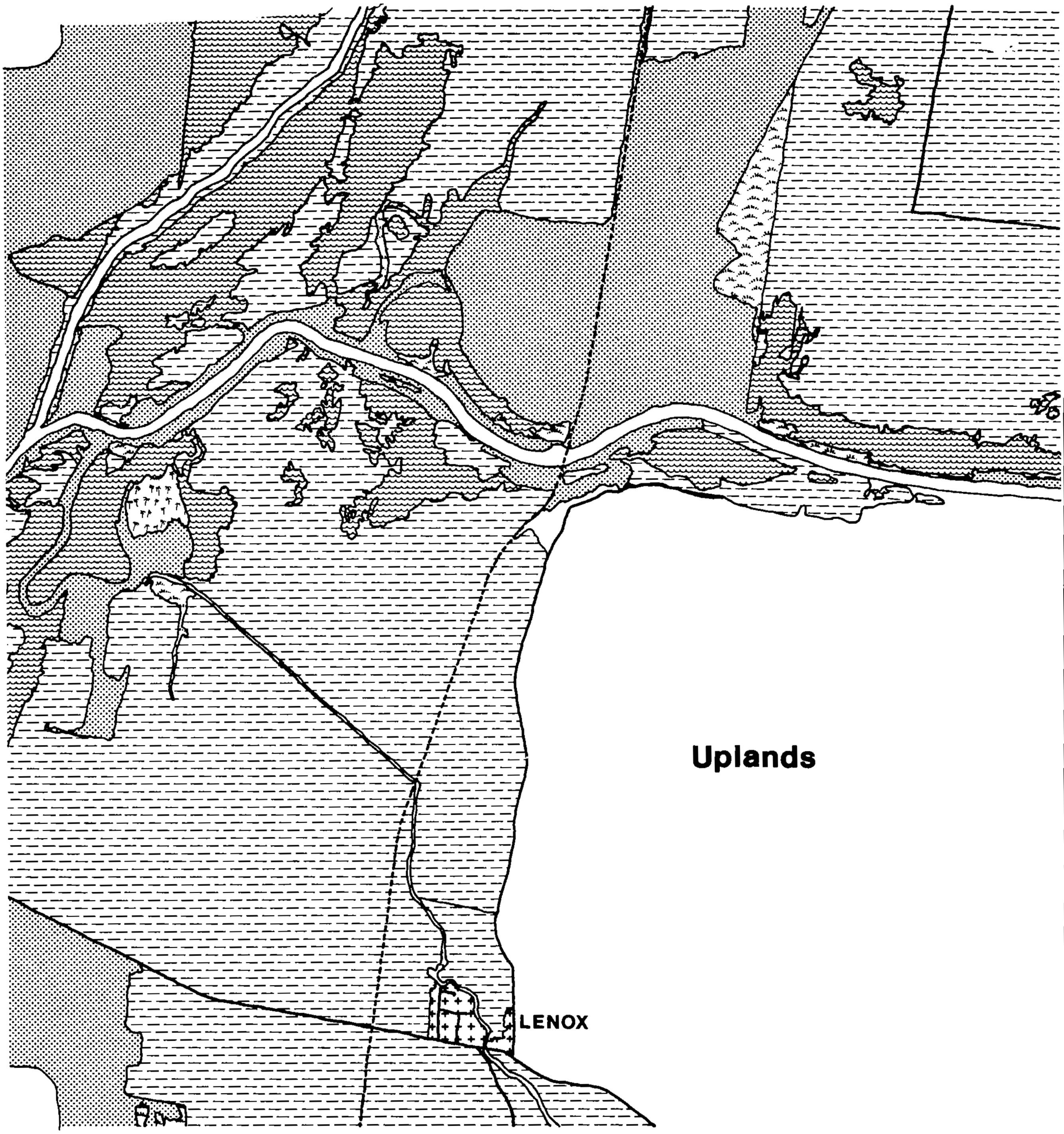
Rivers and Streams

Roads

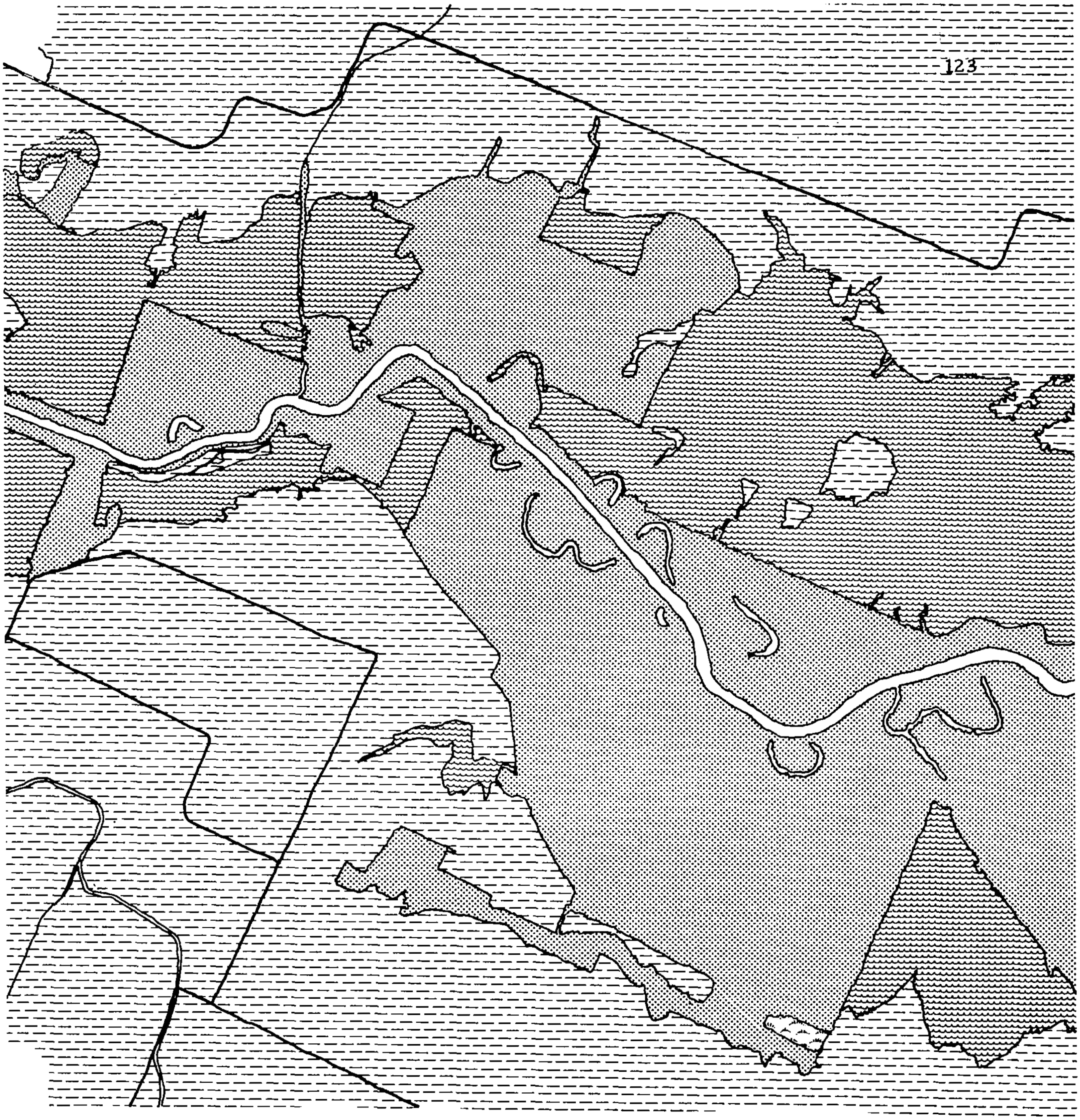
Railroads



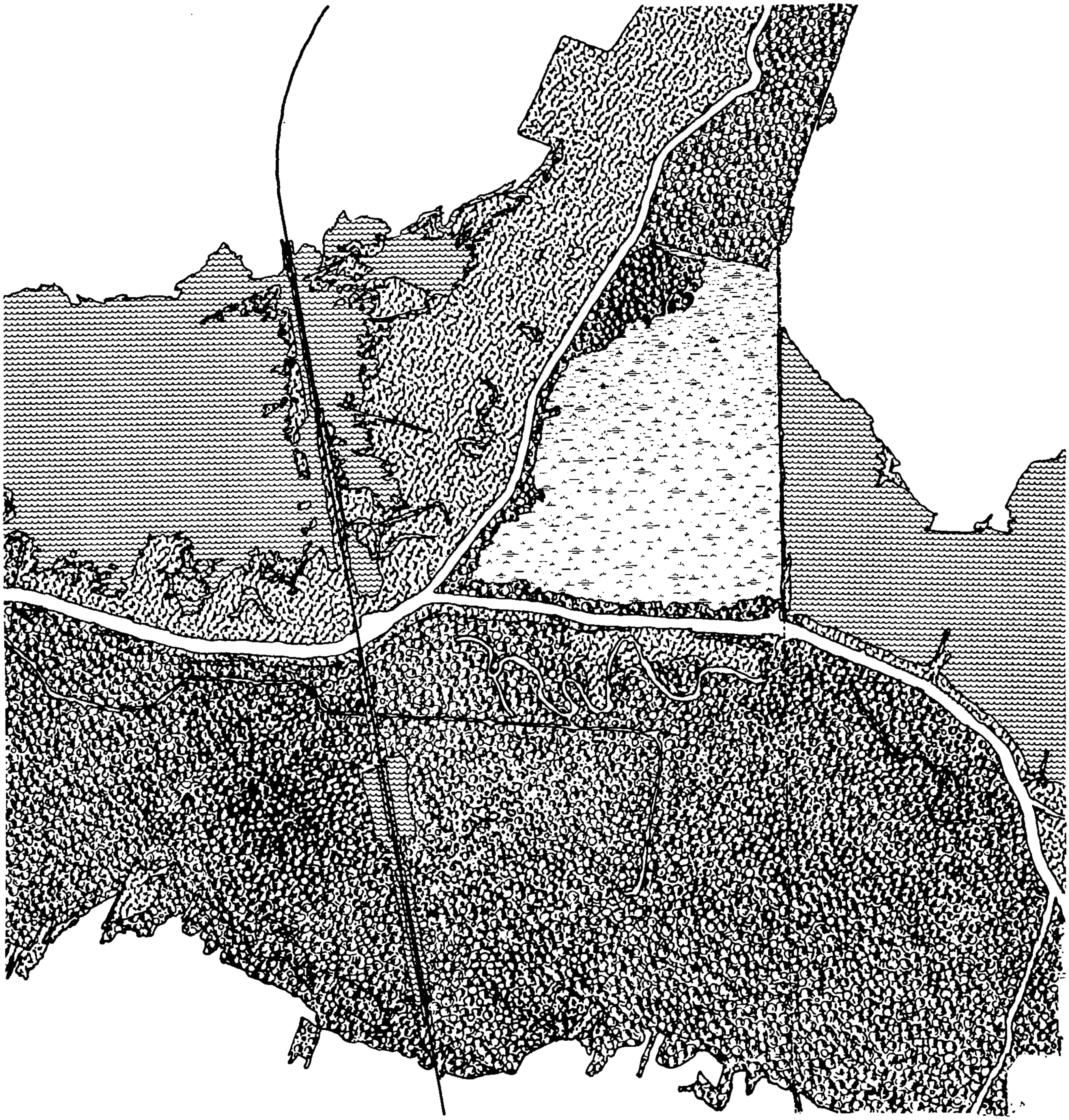
MAP 18
TRANSECT #1 - REELFOOT LAKE AT SAMBURG, TENN.



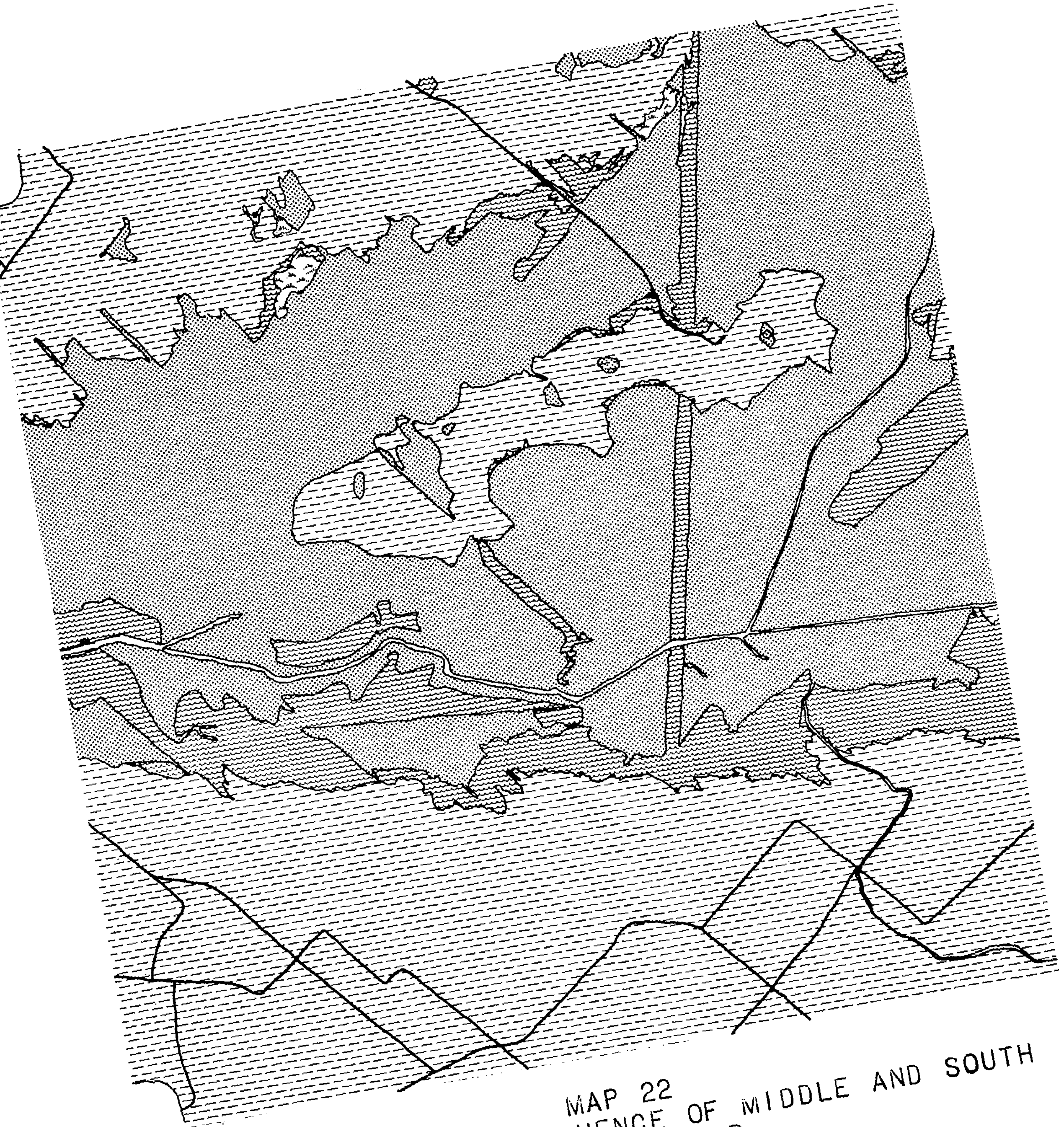
MAP 19
TRANSECT #2 - OBION R. AT RUNNING REELFOOT BAYOU



MAP 20
TRANSECT #3 - LOWER OBION RIVER S.W. OF OBION, TENN.

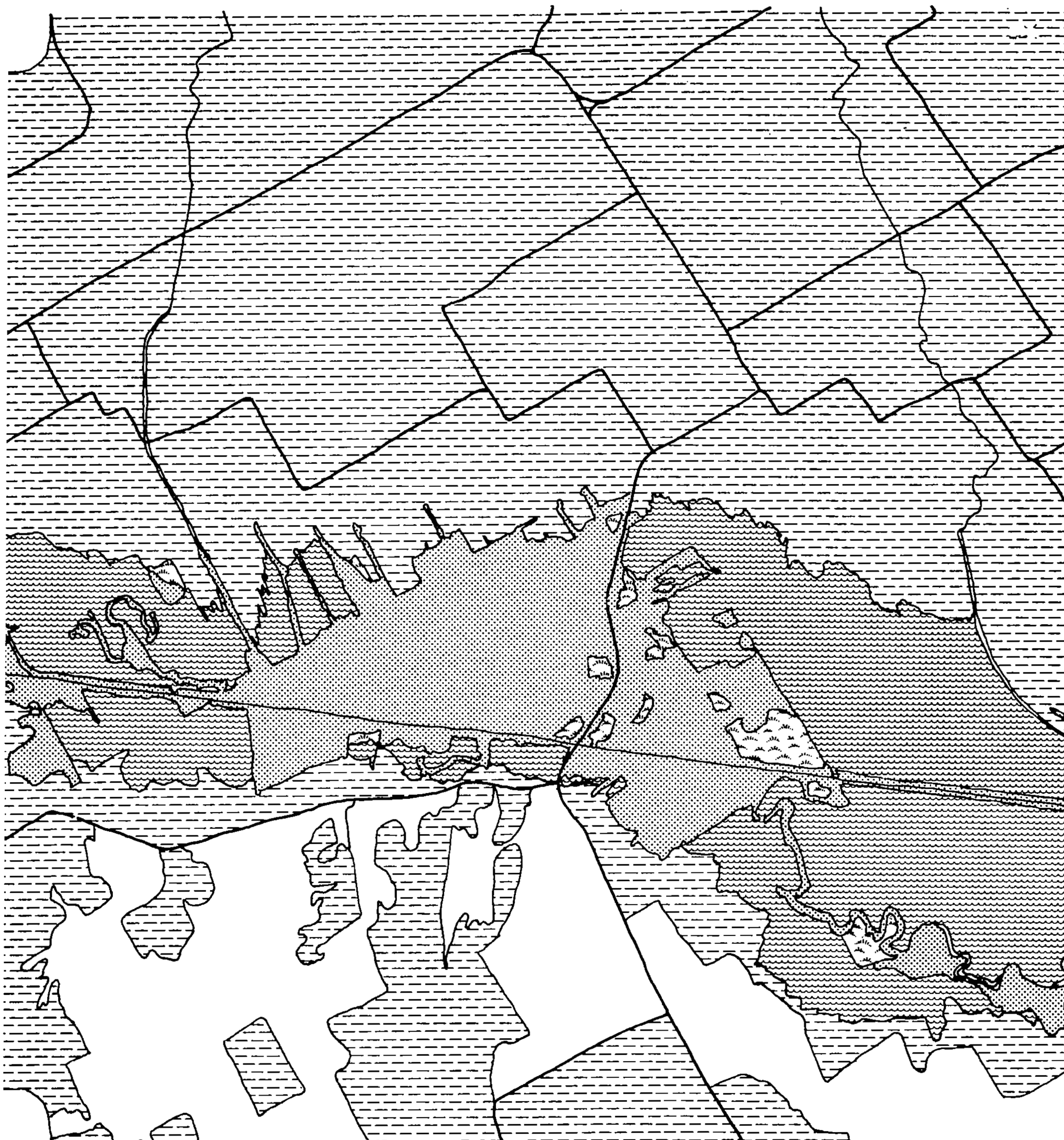


MAP 21
TRANSECT #4 - CONFLUENCE OF N. AND S. FORKS
OBION RIVER



MAP 22

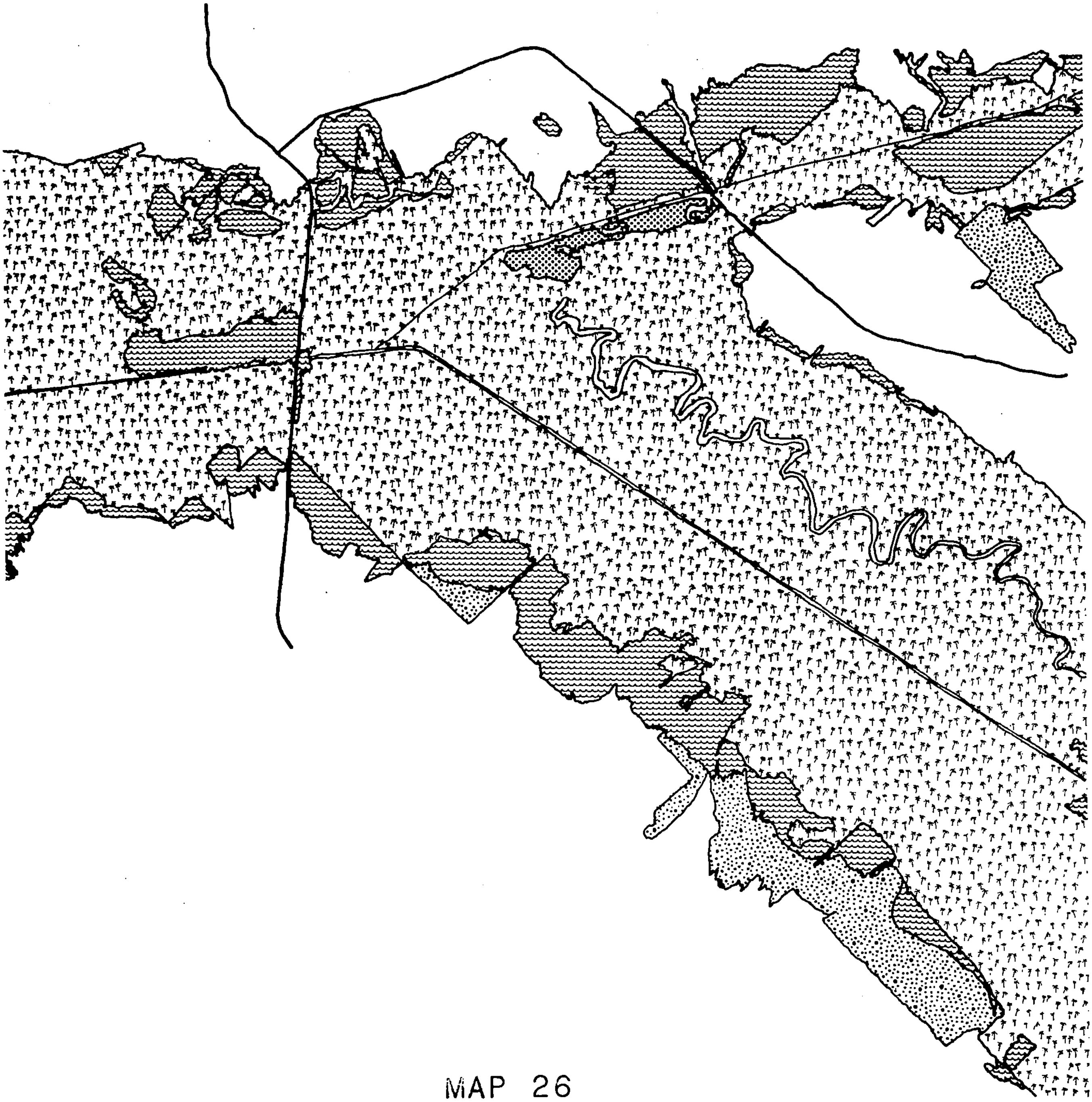
SECT #5 - CONFLUENCE OF MIDDLE AND SOUTH FORKS OBION R.



MAP 23
TRANSECT #6 - RUTHERFORD FK. OBION R. EAST OF DYER, TENN.

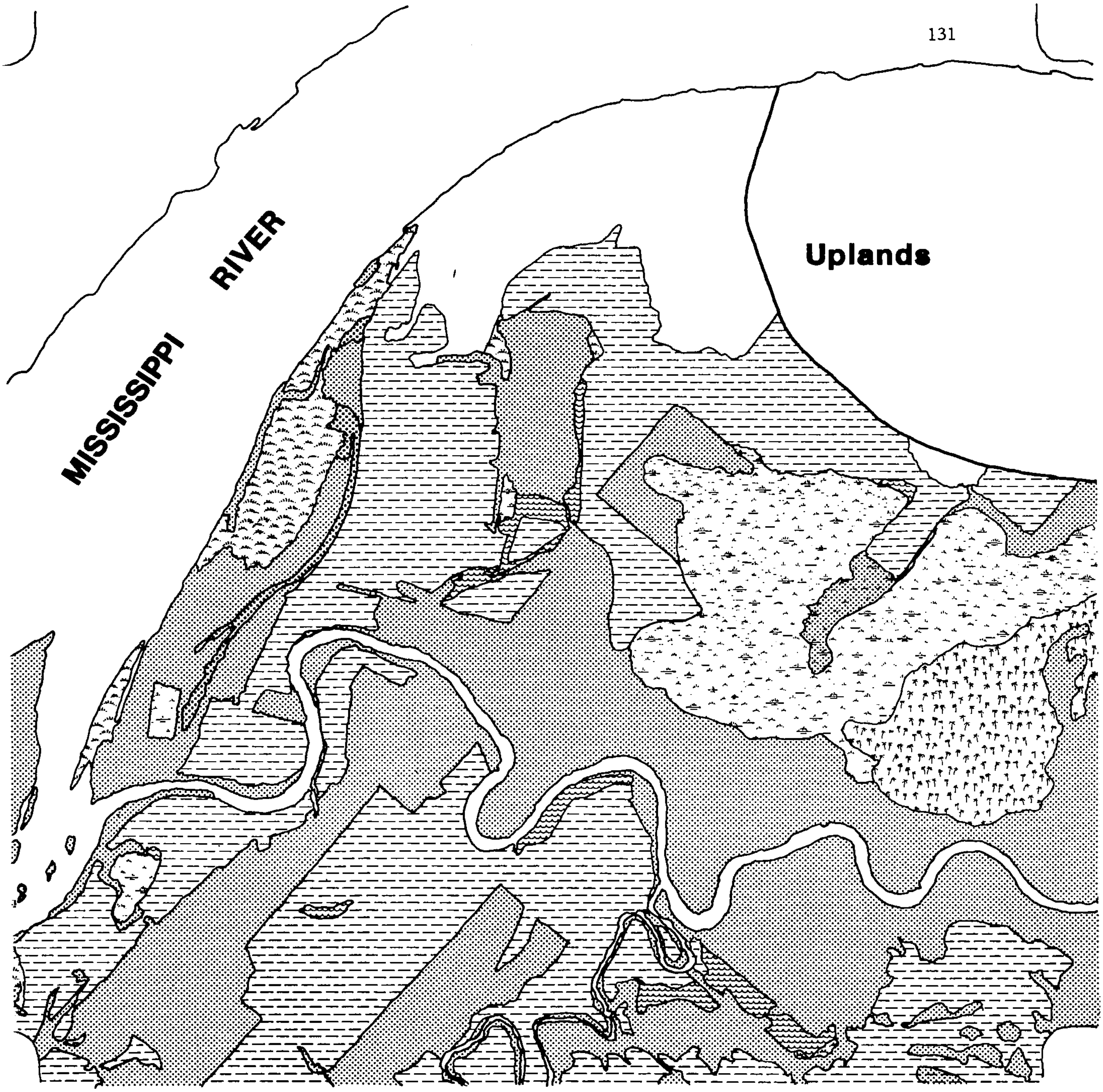
MAP 24
TRANSECT #7 - S. FORK OBION R. AT CONFLUENCE WITH CROOKED CREEK

MAP 25
TRANSECT #8 - CONFLUENCE OF N. AND MIDDLE FORKS FORKED DEER R.

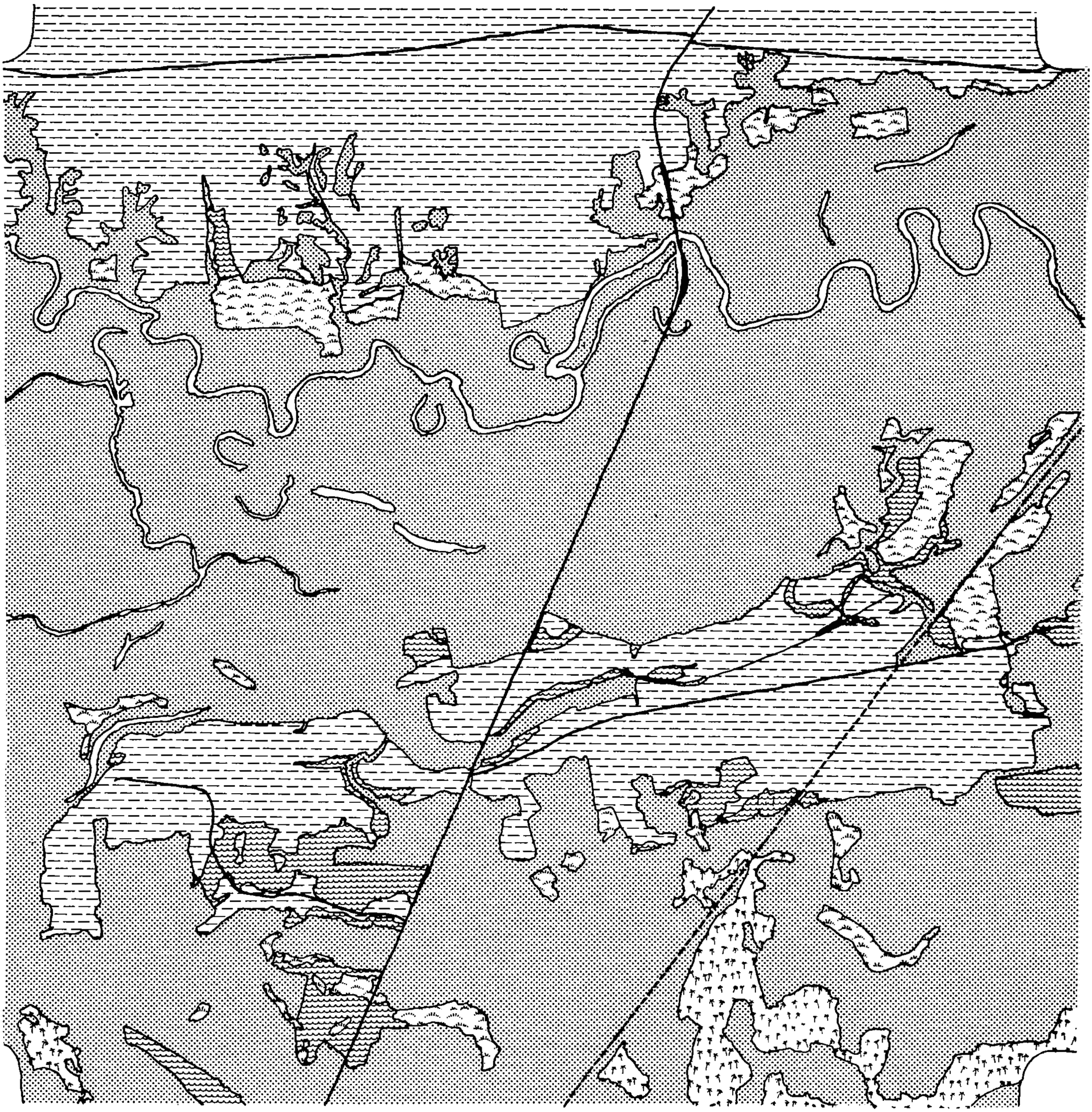


MAP 26
TRANSECT #9 - MIDDLE FORK FORKED DEER R. AT CONFLUENCE WITH BUCK CREEK

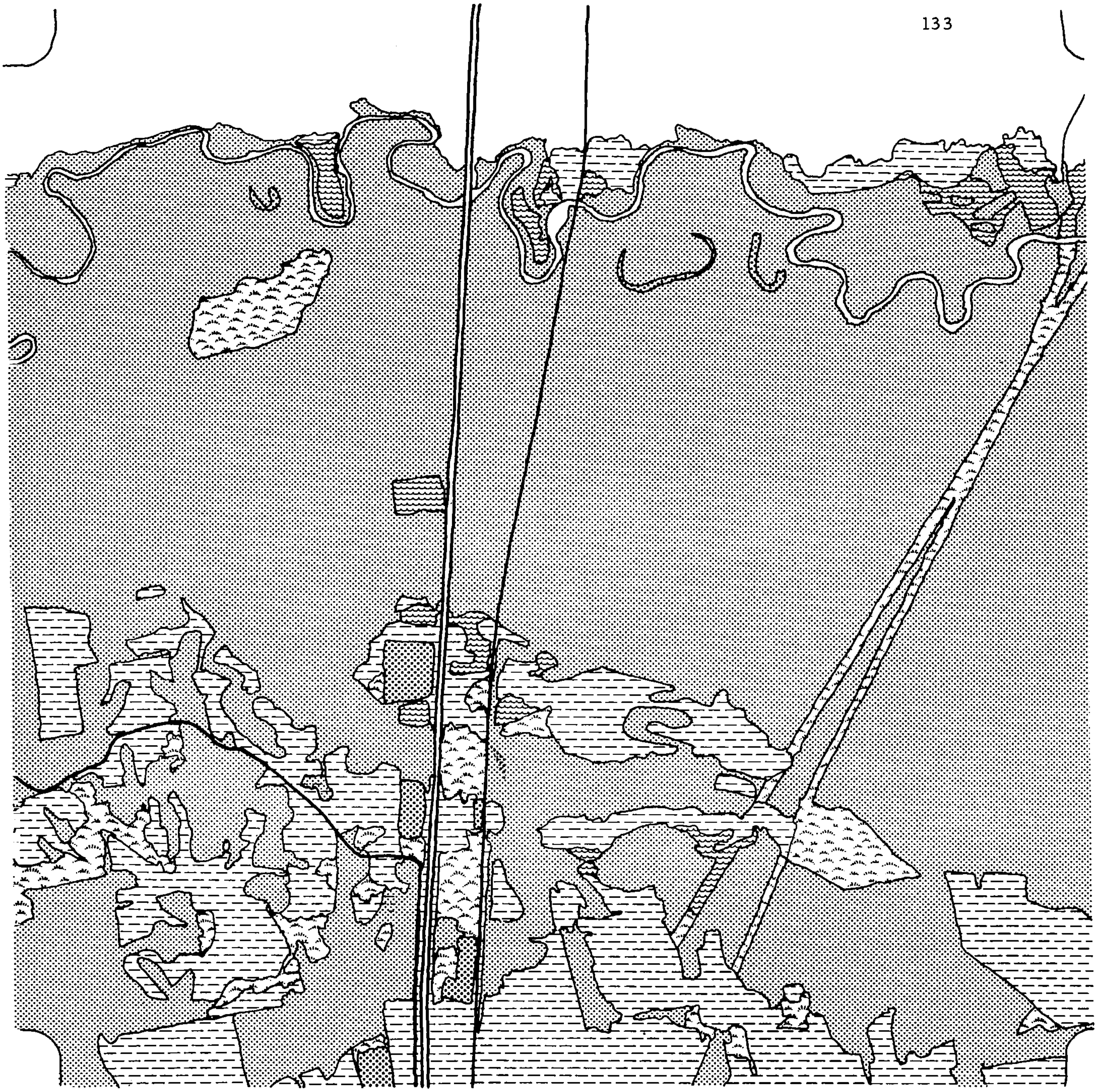
MAP 27
TRANSECT #10 - CONFLUENCE OF NIXON CREEK WITH
S. FORK FORKED DEER R.



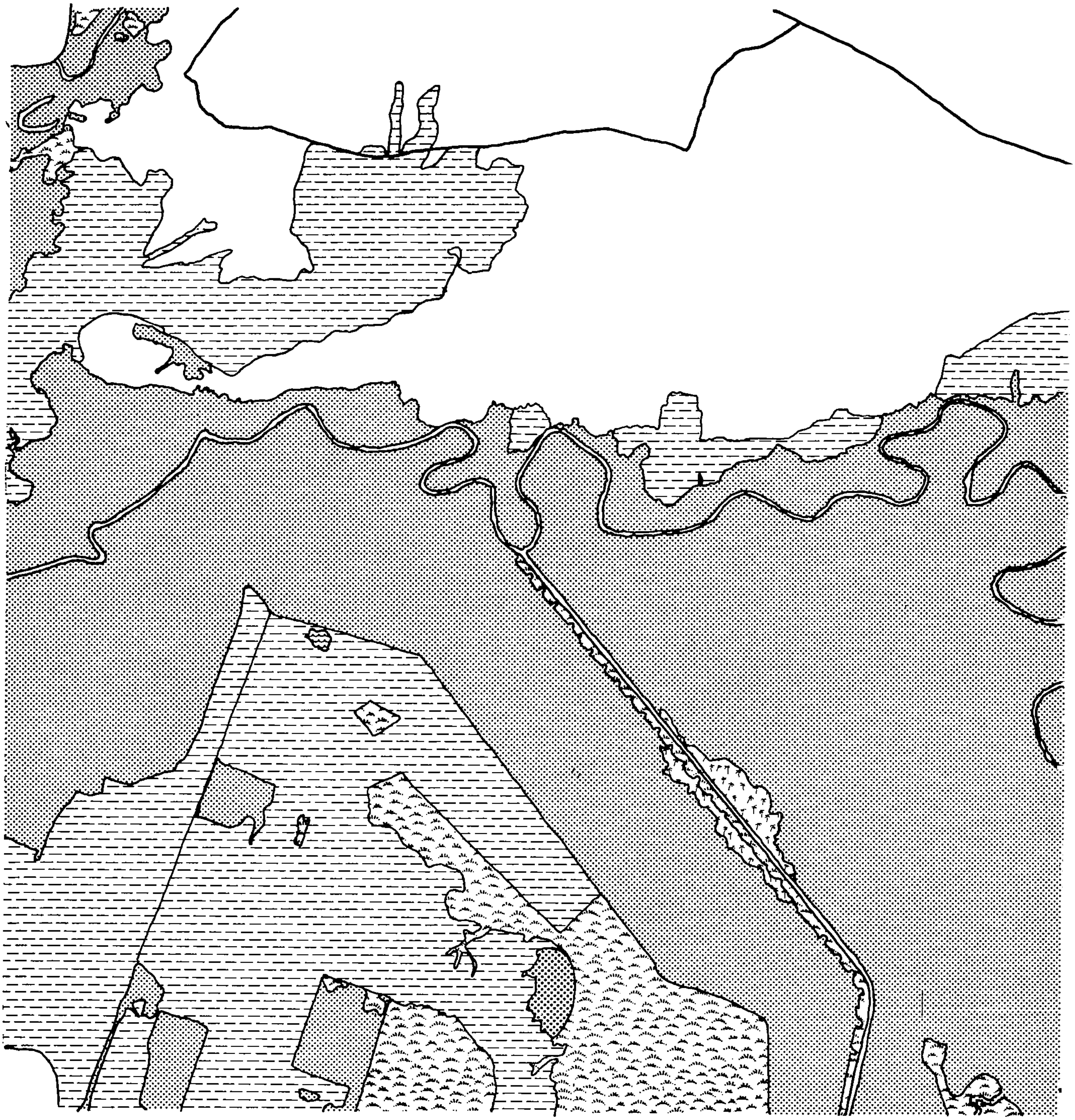
MAP 28
TRANSECT #11 - CONFLUENCE OF HATCHIE R. WITH MISSISSIPPI R.



MAP 29
TRANSECT #12 - HATCHIE R. AT U.S. 79



MAP 30
TRANSECT #13 - HATCHIE R. AT I-40 AND S.R. 76



MAP 31
TRANSECT #14 - HATCHIE R. AT PORTER CREEK CANAL